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Woods Hole Oceanographic Institution

WHOI-2000-03

Technical Report
March 2000

Pan American Climate Study (PACS) Data Report

by

Steven P. Anderson
Kelan Huang
Nancy J. Brink
Mark F. Baumgartner
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March 2000

Upper Ocean Processes Group
Woods Hole Oceanographic Institution
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Approved for Distribution:

Terrence M. Joyce, Chair

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Abstract

The surface mooring component of the NOAA Pan American Climate Study (PACS) took place from April 1997 to September 1998 in the eastern tropical Pacific. PACS was a NOAA funded study with the goal of investigating links between sea surface temperature variability in the tropical oceans near the Americas and climate over the American continents. Two air-sea interaction surface moorings were deployed along 125°W, spanning a strong meridional sea-surface temperature gradient. One mooring site was located in the cold tongue south of the equator, and the other site was in the region of warm ocean found north of the equator, near the northernmost summer location of the Intertropical Convergence Zone. The moorings were deployed to improve our understanding of air-sea fluxes and the processes that control the evolution of the sea surface temperature field in the region.

Four air-sea interaction buoys were deployed to occupy two sites for a period of 17 months. The sites were along 125°W near 3°S and 10°N. The Upper Ocean Processes Group at WHOI deployed the first two moorings in April 1997. These moorings were replaced with a second pair of moorings in December 1997. The final recovery occurred in September 1998. Each of these buoys on these moorings were equipped with meteorological instrumentation, including a Vector Averaging Wind Recorder (VAWR) and an Improved METeorological (IMET) system. The moorings also carried Vector Measuring Current Meters (VMCMS), single point temperature recorders and a few conductivity sensors on the mooring line to monitor the upper 200m of the ocean. In addition to the traditional instruments, several other experimental instruments were deployed with limited success on the mooring line including acoustic current meters, acoustic rain gauges and bio-optical instrument packages

This report describes the instrumentation deployed on the PACS surface moorings, along with information on the processing and quality control of the returned data. It presents a detailed overview of the meteorological and physical oceanographic data including time series plots, statistics and spectra of key parameters. It also presents analysis of the estimated air-sea heat, moisture and momentum fluxes.

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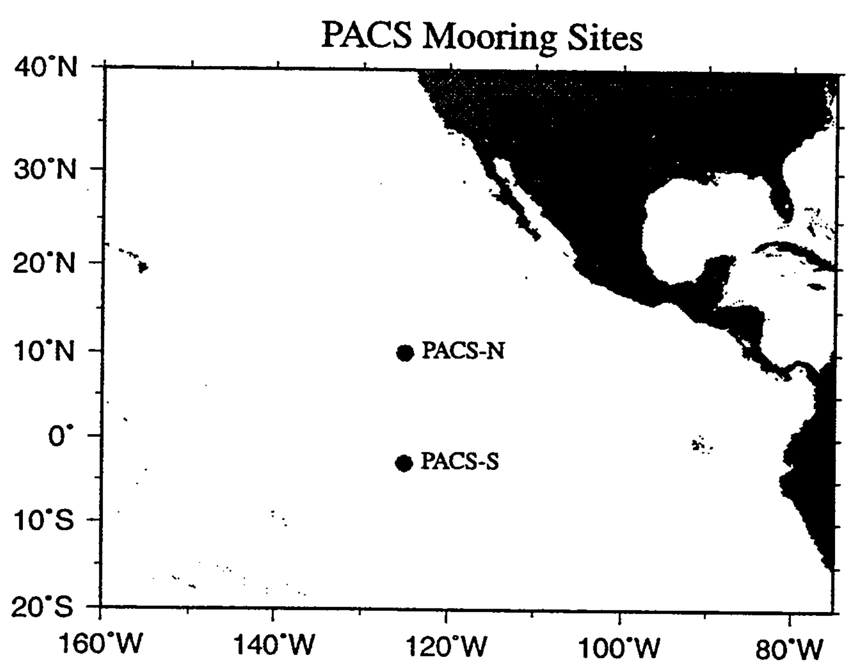
Section 1: Introduction

The sea surface temperature field in the eastern tropical Pacific, with its strong asymmetry about the equator, annual and interannual variability, and links to climate are of great interest to the NOAA Pan American Climate Study (PACS) Program. The sea surface temperature field is believed to control the strength and location of the Inter-Tropical Convergence Zone (ITCZ); and this variability in the ITCZ may in turn influence the location of the jet stream and precipitation over North America. However, our understanding of the processes that control sea surface temperature in this region is lacking and uncertainties in existing climatologies of the surface heat flux, wind stress, and precipitation are large. The ITCZ and the warm water north of the equator both move north and south annually, but the details of the coupling between the two are unknown.

From April 1997 through September 1998, in a study for PACS, sites at 3°S and 10°N along 125°W were occupied with air-sea interaction surface moorings equipped to collect accurate time series of surface meteorology and upper ocean temperature, velocity, and salinity structure (Figure 1-1). The two sites span strong gradients in ocean temperature, from the cold tongue just south of the equator to the warm waters north of the equator, and gradients in cloud cover and precipitation associated with the location of the ITCZ.

Figure 1-1. PACS Equatorial Pacific Mooring Locations



Each mooring carried two complete sets of meteorological sensors (wind speed and direction, air and sea temperature, incoming short-wave radiation and incoming long-wave radiation, humidity, barometric pressure, precipitation). Both the Vector Averaging Wind Recorder (VAWR; Weller *et al.*, 1990) and Improved Meteorological (IMET; Hosom *et al.*, 1995) systems were used in redundancy to ensure that a complete and accurate time series of all meteorological variables would be collected. The moorings also carried oceanographic sensors (temperature, conductivity and current) placed in the top 200 m of the ocean to monitor the upper ocean variability.

The meteorological data permit the accurate calculation of the heat, freshwater, and momentum fluxes across the air-sea interface via the bulk formulae using techniques perfected in the Tropical Ocean-Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA COARE; Fairall *et al.*, 1996a). Data from the moorings will improve our understanding of the air-sea fluxes in the eastern tropical Pacific and the processes that control sea surface temperature.

The moorings were deployed in April 1997 from the R/V *Roger Revelle*, serviced in December 1997 from the R/V *Thomas Thompson* and recovered in September 1998 from the R/V *Melville*. A detailed description of the field work can be found in the cruise reports (Way, *et al.*, 1998, Trask *et al.*, 1998 and Ostrom *et al.*, 1999). Meteorological and hydrographic data were collected during all three of these cruises to complement the moored time series data. These new observations were made along an existing north-south line of the TOGA Tropical Atmosphere and Ocean (TAO) mooring array, which provides a larger time and space context for the work and a means to examine the effects of remote forcing.

This report documents the meteorological and oceanographic data returned from the PACS surface moorings. Section 2 describes the instrumentation used on the moorings. Section 3 describes the data processes and quality control. Time series plots, statistics and spectra of key parameters in Section 4 for the northern site and Section 5 for the southern site.

Note that the first buoy deployments covering the time period from April-December 1997 will be noted as PACS1 and the second deployments covering the time period from December 1997 to September 1998 as PACS2. The buoys deployed near 10°N are noted as NORTH (N) and those near 3°S as SOUTH (S). The specific times and locations are given in Table 1-1, 1-2.

Table 1-1 PACS 1 mooring deployment/recovery information

Mooring	Deployment Date and Time	Recovery Date	Anchor Position
WHOI PACS - South Discus Buoy WHOI Mooring Reference No. 1014	21 April 1997 @0002 UTC	7 December 1997 @1548 UTC	2°46.78'S 124°39.38'W
WHOI PACS - North Discus Buoy WHOI Mooring Reference No. 1015	29 April 1997 @2135 UTC	17 December 1997 @ 1533 UTC	9°58.99'N 125°23.39'W

Table 1-2 PACS 2 mooring deployment/recovery information

Mooring	Deployment Date and Time	Recovery Date	Anchor Position
WHOI PACS South Discus Buoy WHOI Mooring Reference No. 1020	9 December 1997 @ 0036 UTC	20 September 1998 @1429 UTC	2° 46.231'S 124° 39.733'W
WHOI PACS North Discus Buoy WHOI Mooring Reference No. 1021	19 December 1997 @ 0119 UTC	14 September 1998 @1429 UTC	9° 55.787' N 125° 24.772'W

Section 2: Instrumentation

Details about each type of instrument on the PACS moorings are provided below beginning with the meteorological instrumentation and then followed by the subsurface instrumentation. Specific information about the instrumentation deployed during PACS1 can be found in Way *et al.,* 1998 and for PACS2 in Trask *et al.*, 1998.

The instrumented buoy is shown in Figure 2-1-1 and the tower top plan view layout for PACS1 and PACS2 is provided in Figure 2-1-2. PACS1 and PACS2 North mooring schematics are show in Figure 2-1-3 and 2-1-4. PACS1 and PACS2 South mooring schematics are shown in Figures 2-1-5 and 2-1-6. Blow-ups of the buoy tower and bridle for all four moorings are shown in Figures 2-1-7, 2-1-8, 2-1-9, and 2-1-10.

2-1. Meteorological Instrumentation

The WHOI discus buoys were outfitted with two separate meteorological packages. One system was a VAWR which logged and telemetered data from eight meteorological sensors. The second meteorological data recording system called IMET logged data from nine meteorological sensors and this data was also telemetered. On the PACS1 deployment both buoys had a stand-alone, internally recording instrument that measured relative humidity and air temperature. In addition to the VAWR and IMET systems deployed on the PACS2 buoys, there was also a stand-alone, internally recording instrument that measured precipitation as well as another that measured both relative humidity and air temperature. The relative humidity instrument deployed on PACS2 is an improved version of the IMET relative humidity module in that it was self-powered and recorded its data internally. It was part of a family of instruments called ASIMET which have been in use on Volunteer Observing Ships (VOS).

Figure 2-1-2 show a plan view layout of the meteorological instrumentation mounted on the PACS1 and PACS2 WHOI discus buoys. Tables 2-1-1 and 2-1-2 list the buoy-mounted instrumentation on the PACS1 and PACS2 North. Tables 2-1-3 and 2-1-4 list the buoy-mounted instrumentation on PACS1 and PACS2 South, respectively. The information listed includes sensor identification and sensor height with respect to the water line. The height of all buoy-mounted instrumentation is referenced to the buoy deck and the water line.

Figure 2-1-1. Photo of PACS South Instrumented Buoy

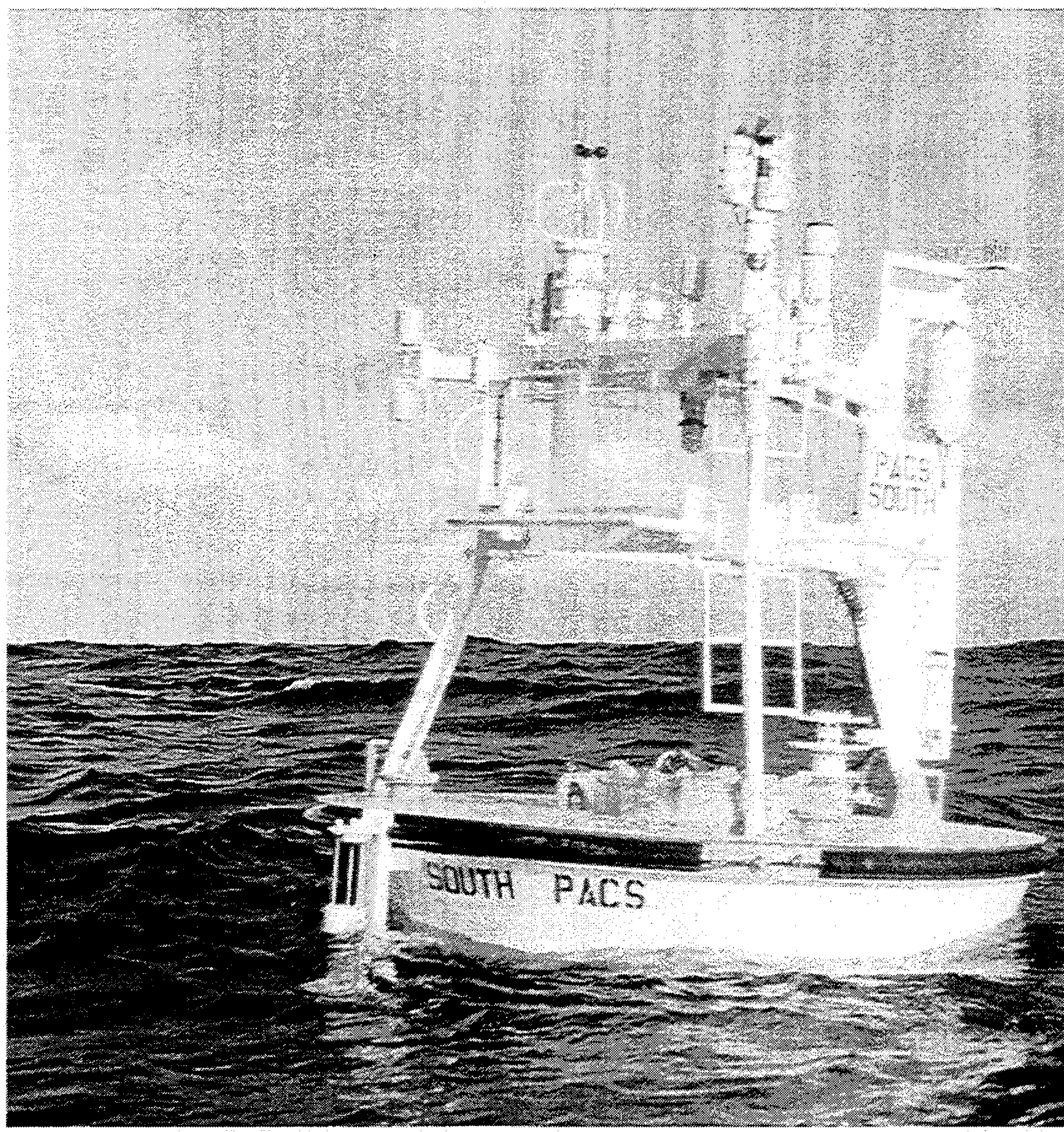
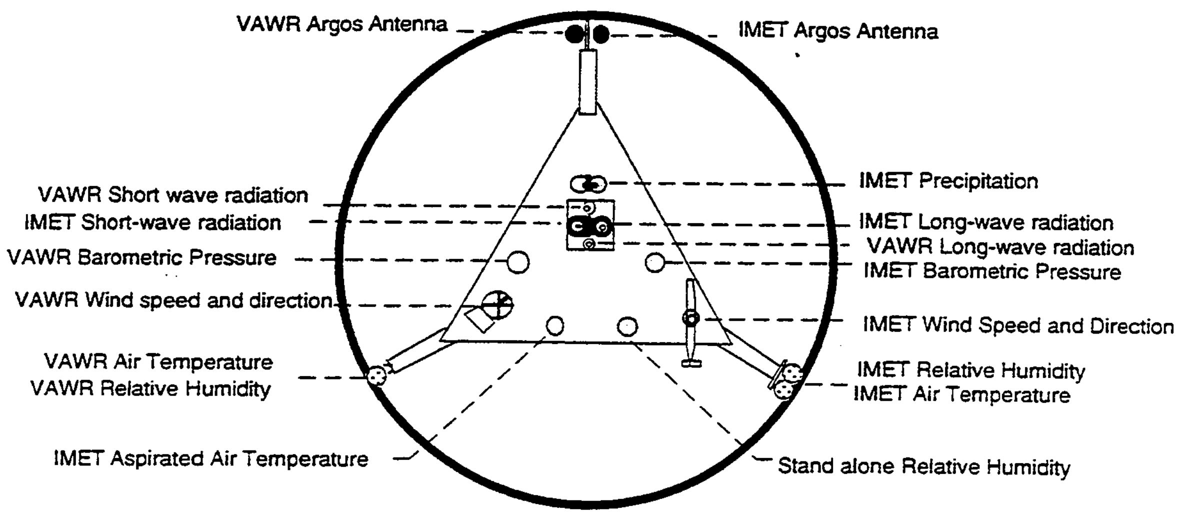
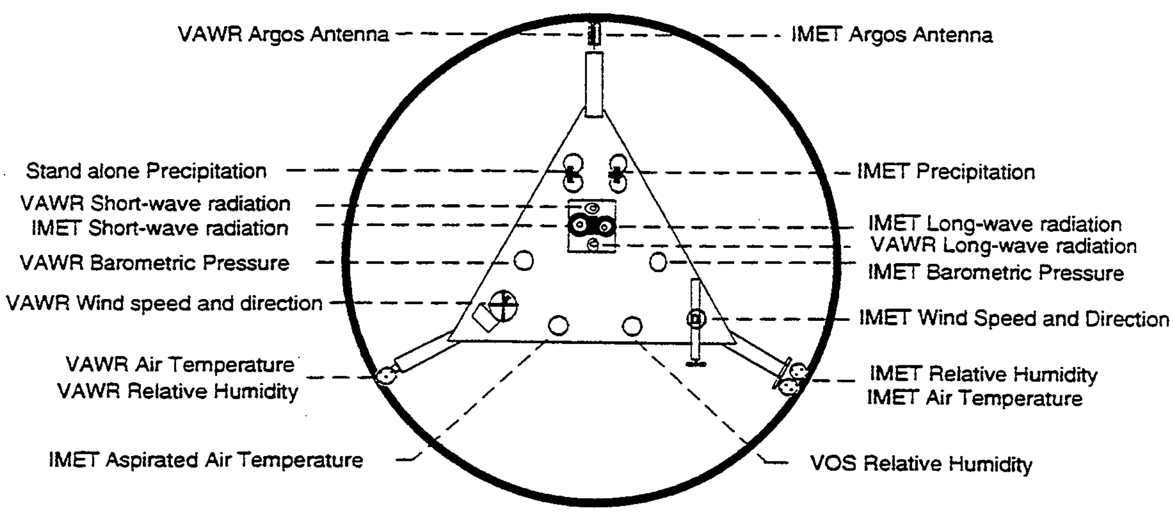


Figure 2-1-2. PACS Tower Top Layout



PACS 1 Discus Buoy Tower Layout



PACS 2 Discus Buoy Tower Layout

Figure 2-1-3. Schematic of PACS1 North Mooring.

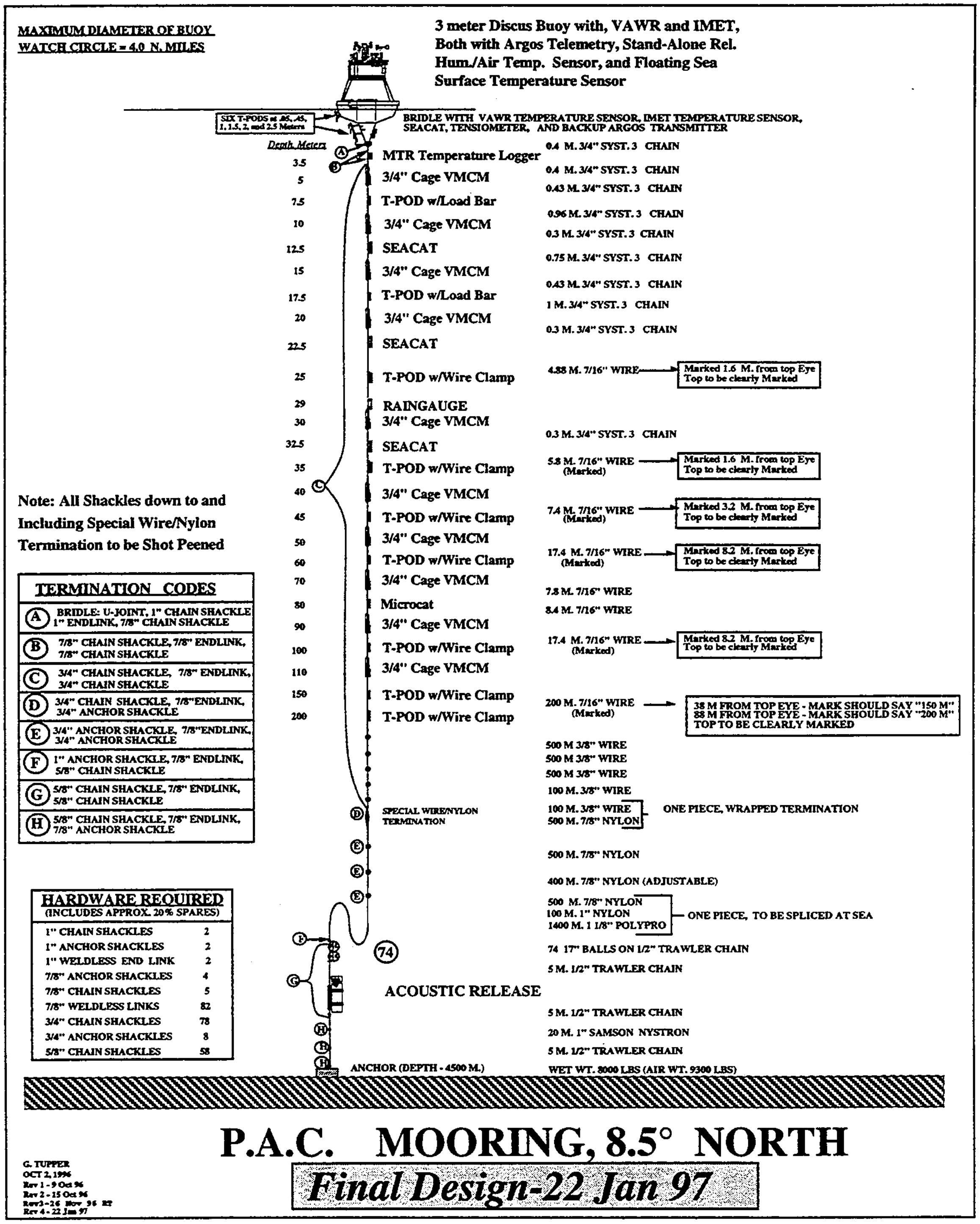


Figure 2-1-4. Schematic of PACS2 North Mooring.

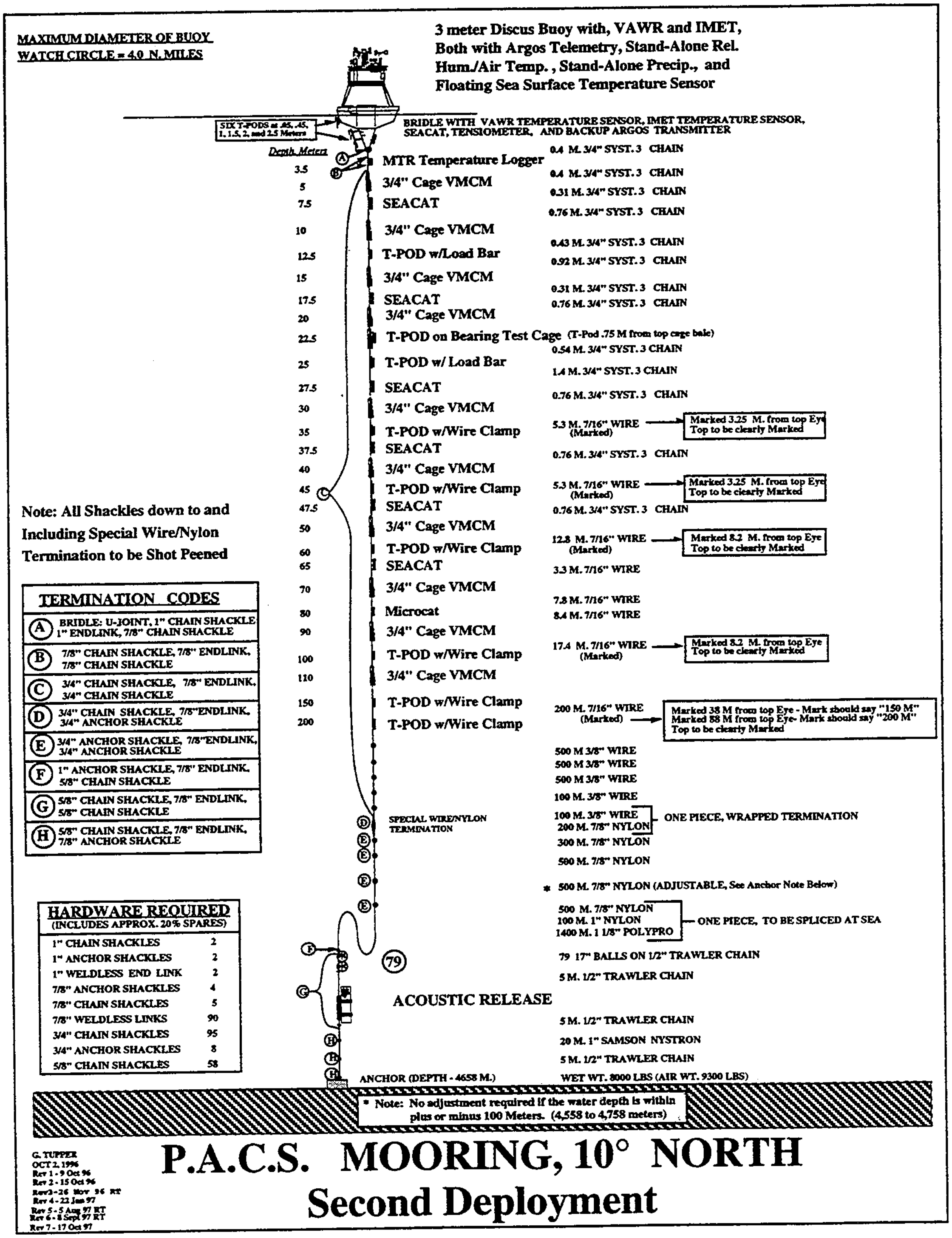


Figure 2-1-5. Schematic of PACS1 South Mooring.

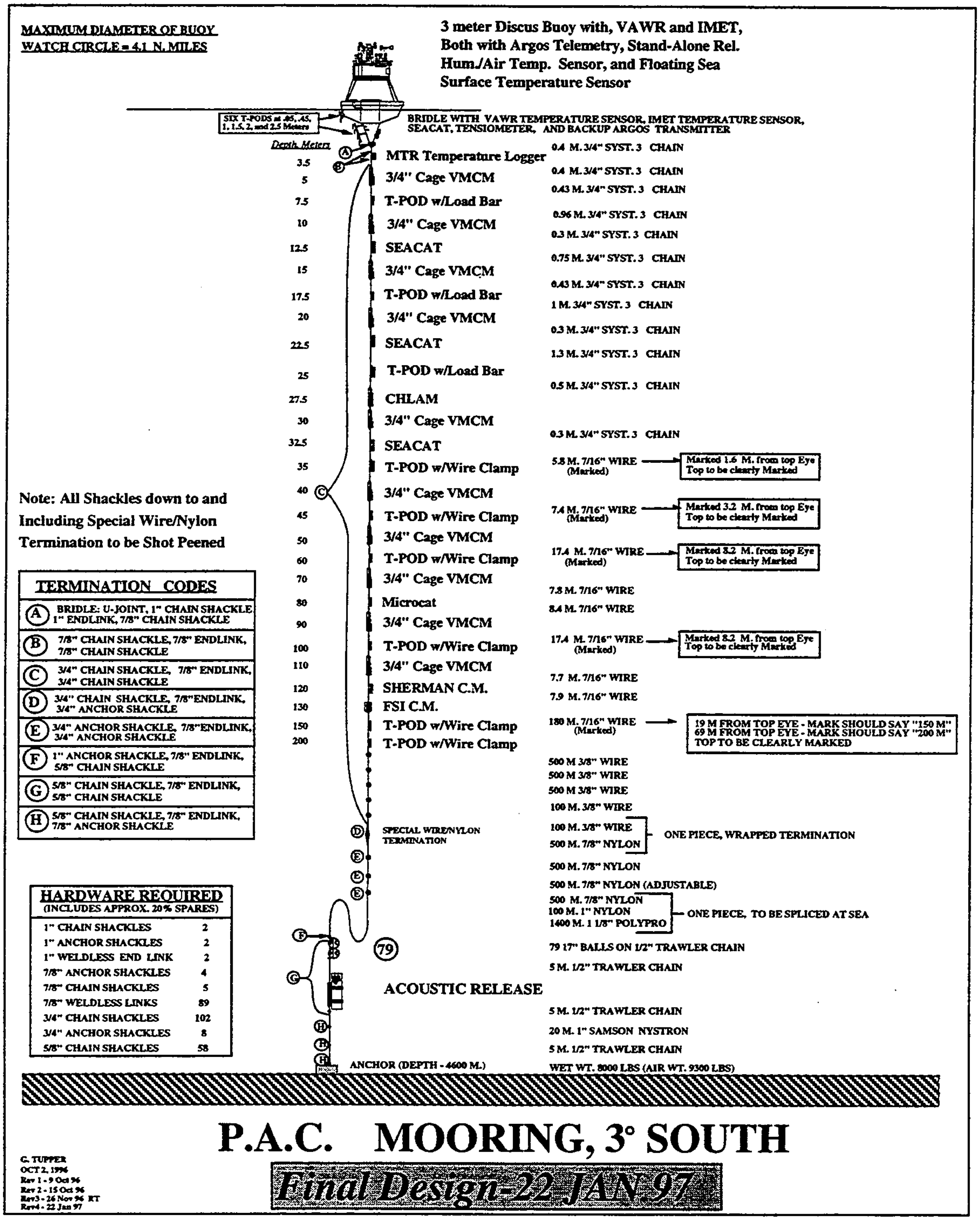


Figure 2-1-6. Schematic of PACS2 South Mooring.

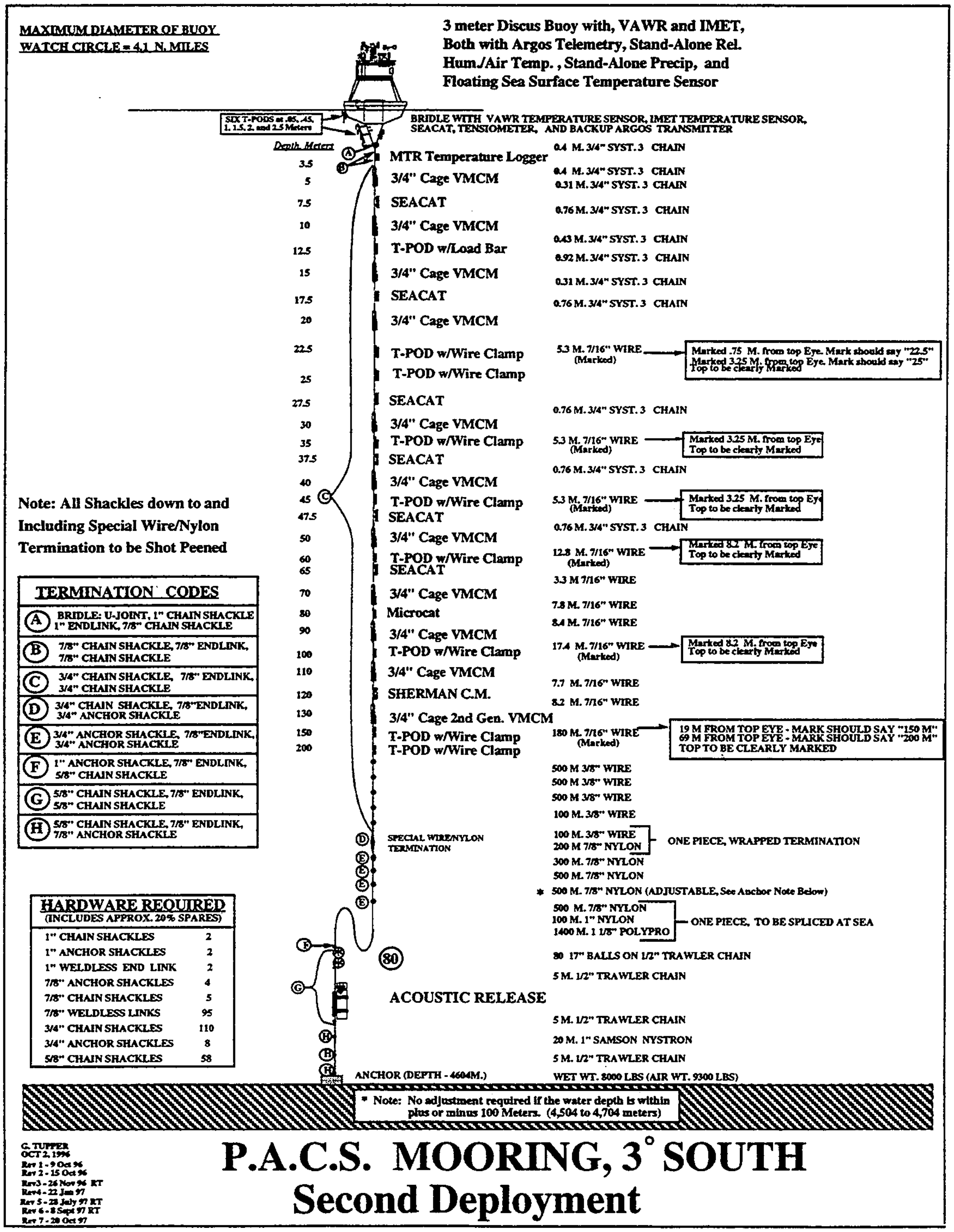


Figure 2-1-7. Tower Top Instrumentation on PACS1 North Buoy.

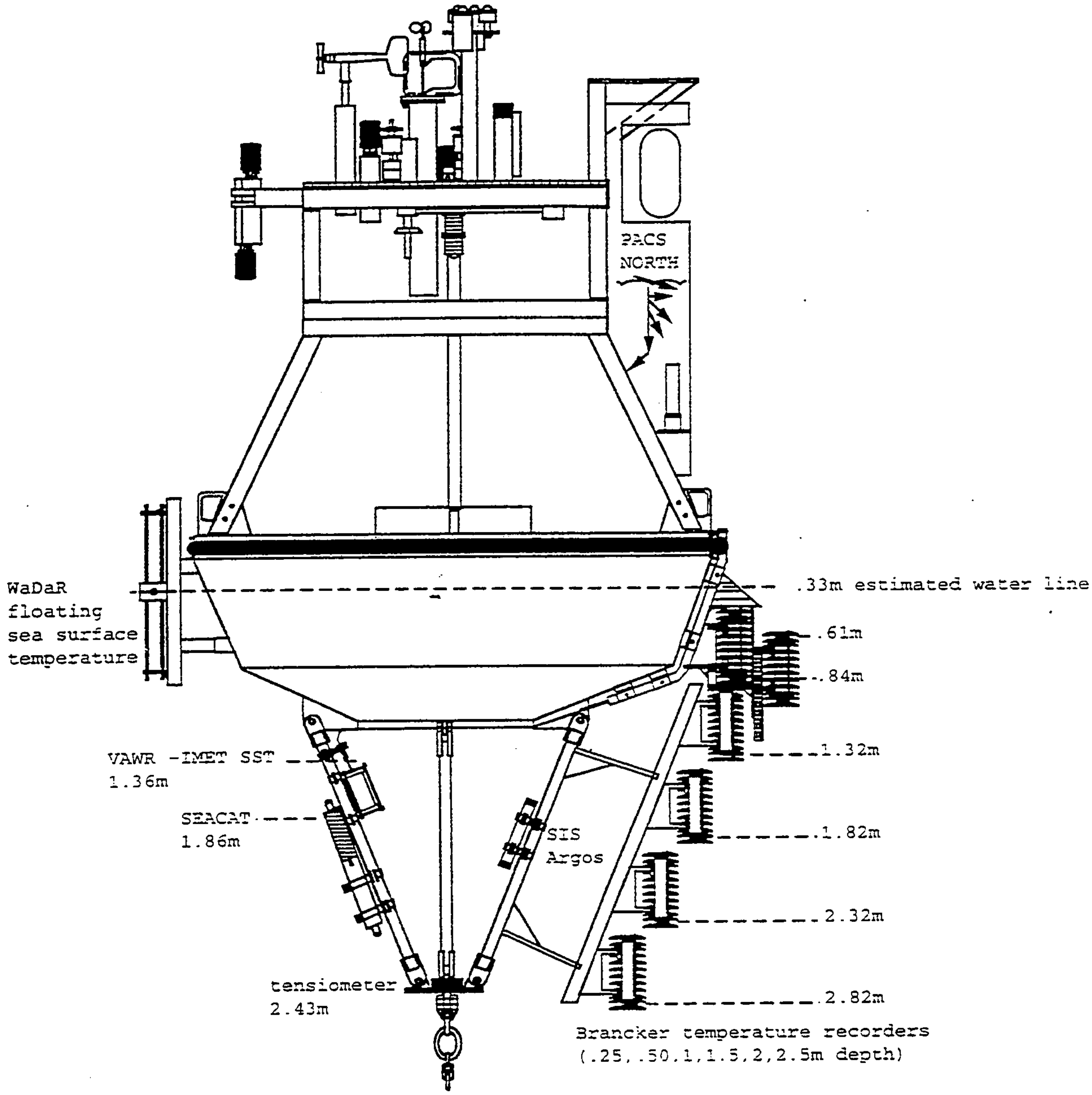


Figure 2-1-8. Tower Top Instrumentation on PACS2 North Buoy.

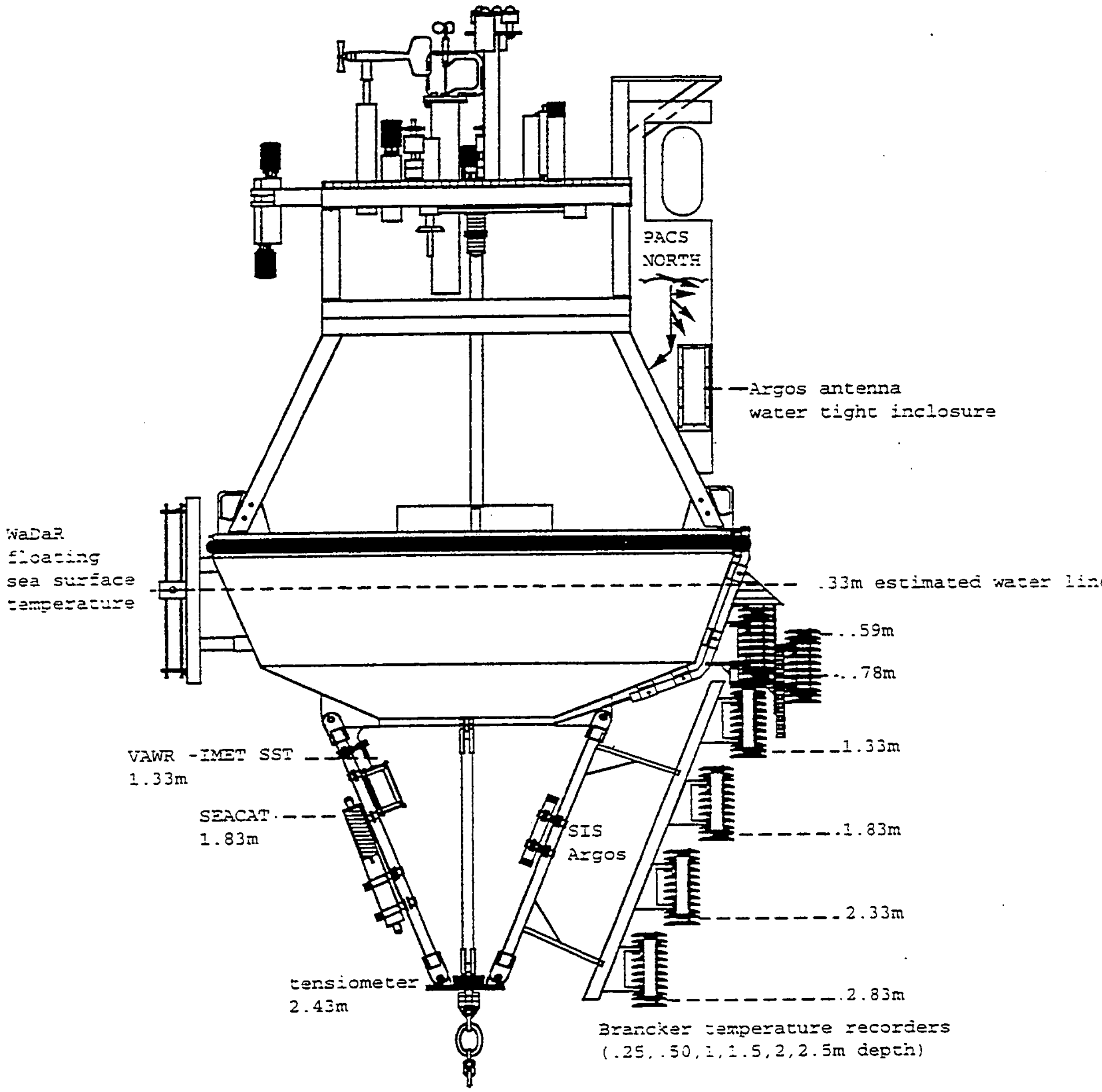


Figure 2-1-9. Tower Top Instrumentation on PACS1 South Buoy.

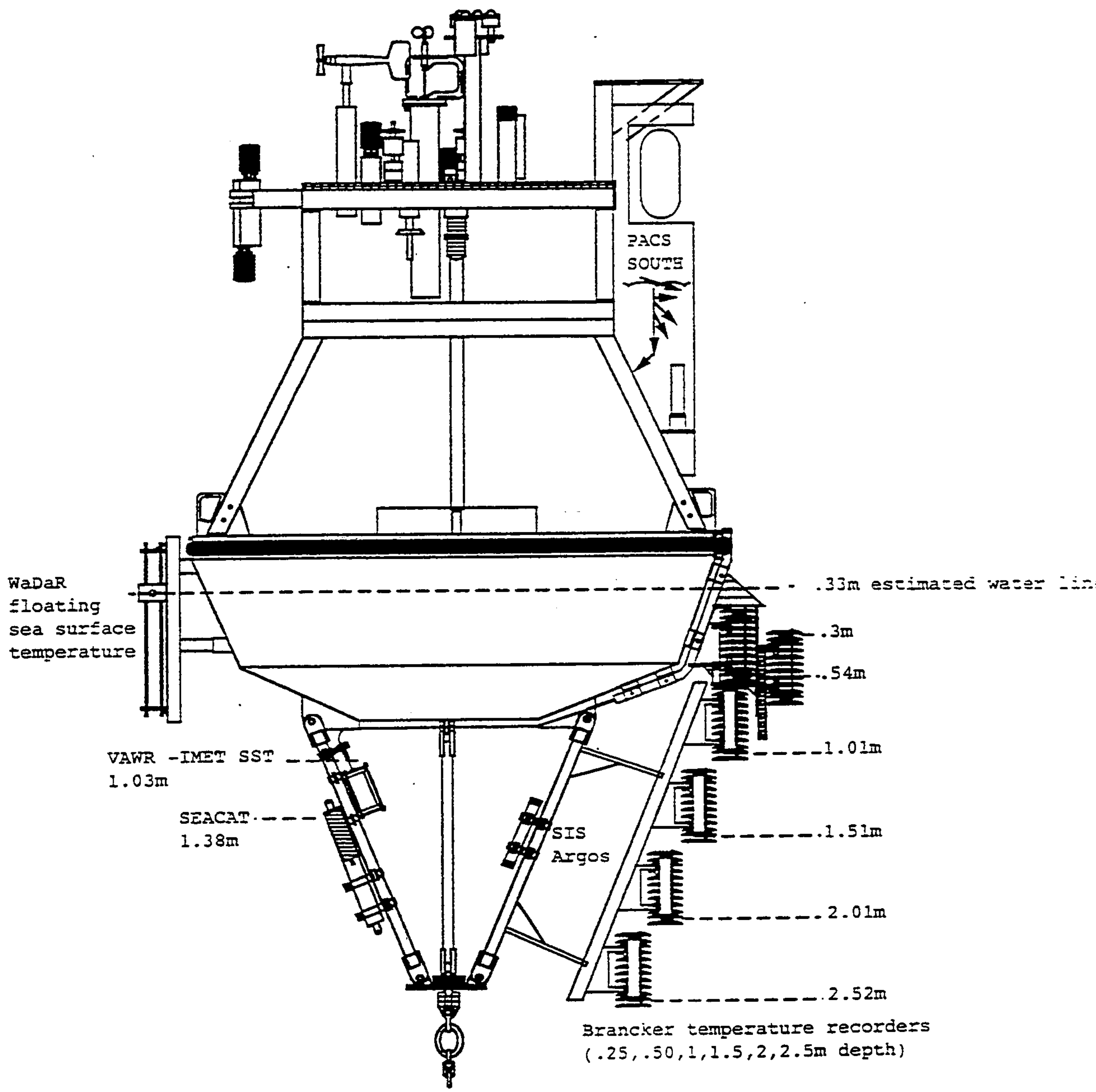


Figure 2-1-10. Tower Top Instrumentation on PACS2 South Buoy.

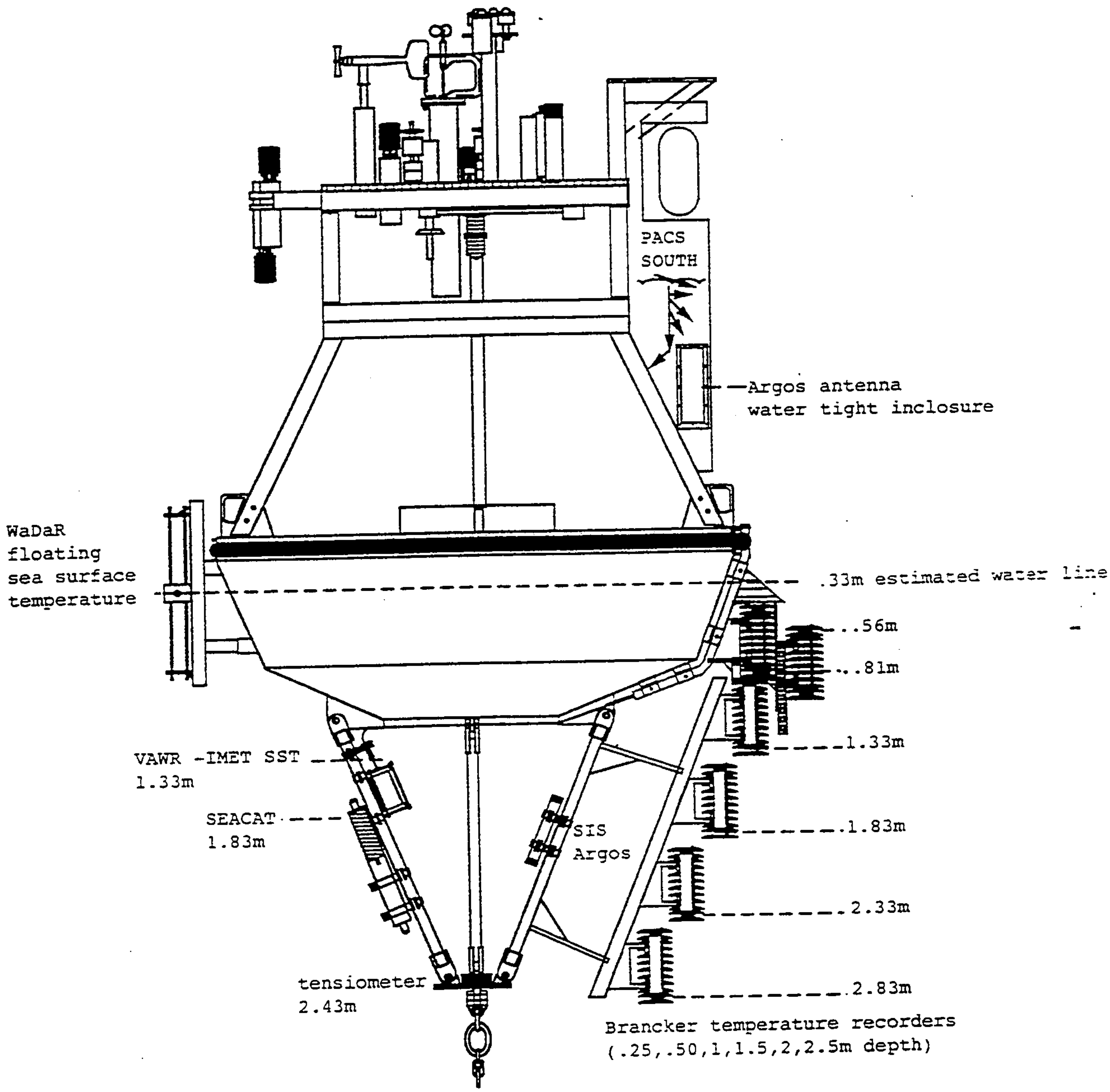


Table 2-1-1. PACS1 North discus buoy-mounted sensors and corresponding elevations.

Parameter	Sensor ID	Elevation relative to buoy deck [meters]	Elevation relative to water line [meters]	Measurement Location
IMET	Logger 295			
Wind speed	WND 111	2.90	3.26	Prop Axis
Wind direction	WND 111	2.90	3.26	Prop Axis
Air temperature	TMP 105	1.63	1.99	End of Probe
Aspirated air temperature	TMP 101	1.85	2.21	End of Probe
Relative humidity	HRH 107	2.37	2.73	Tip of Sensor
Barometric pressure	BPR 107	2.36	2.72	Center of port
Precipitation	PRC 102	2.73	3.09	Top of funnel
Long-wave radiation	LWR 006	3.05	3.41	Base of dome
Short-wave radiation	SWR 111	3.05	3.41	Base of dome
Sea temperature	SST 109	-1.36	-1.00	End of Probe
VAWR	V722WR			
Wind speed	V722WR	2.97	3.33	Center of Cups
Wind direction	V722WR			
Air temperature	5815	1.80	2.16	End of Probe
Relative humidity	V-028-001	2.17	2.53	Tip of Sensor
Barometric pressure	44141	2.38	2.74	Center of port
Long-wave radiation	28459	3.05	3.41	Base of dome
Short-wave radiation	26257	3.05	3.41	
Sea temperature	5005	-1.36	-1.00	End of probe
Stand-alone relative humidity	008	2.38	2.74	
SEACAT conductivity/temp	994	-1.86	-1.50	At temperature probe
Floating sea surface temp	WADAR 275		-0.05	
Temperature recorder	3263	-0.61	-0.28	Thermistor end
Temperature recorder	4491	-0.84	-0.51	Thermistor end
Temperature recorder	4483	-1.32	-0.99	Thermistor end
Temperature recorder	3258	-1.82	-1.49	Thermistor end
Temperature recorder	3838	-2.32	-1.99	Thermistor end
Temperature recorder	3704	-2.82	-2.43	Thermistor end
Tension cell	94033	Base of bridle		

Distance between buoy deck and water line was .33 meters

Table 2-1-2. PACS2 North discus buoy-mounted sensors and corresponding elevations.

Parameter	Sensor ID	Elevation relative to buoy deck (meters)	Elevation relative to water line (meters)	Measurement location
IMET	Logger 291			
Wind speed	WND 113	2.95	3.28	Prop Axis
Wind direction	WND 113	2.95	3.28	Prop Axis
Air temperature	TMP 110	1.74	2.40	Mid shield
Aspirated air temp	TMP 102	1.85	2.18	Tip of Probe
Relative humidity	HRH 111	2.2	2.53	Mid shield
Barometric pressure	BPR 105	2.39	2.72	Center of port
Precipitation	PRC 108	2.74	3.07	Top of funnel
Long-wave radiation	LWR 101 (28908)	3.06	3.39	Base of dome
Short-wave radiation	SWR 002	3.06	3.39	Base of dome
Sea temperature	SST 106	-1.33	-1.00	End of Probe
VAWR	V721WR			
Wind speed	V721WR	2.97	3.30	Center of Cups
Wind direction	V721WR	2.71	3.04	Mid vane
Air temperature	5824	1.79	2.12	Mid Shield
Relative humidity	V-022-01	2.14	2.47	Mid Shield
Barometric pressure	55796	2.39	2.72	Center of port
Long-wave radiation	21787	3.06	3.39	Base of dome
Short-wave radiation	24103	3.06	3.39	Base of dome
Sea temperature	5523	-1.33	-1.00	End of probe
Stand-alone precipitation	004	2.73	3.06	Top of funnel
ASIMET relative humidity	HRH 204	2.47	2.80	Mid Shield
Floating sea surface temperature	WaDaR 272		-0.05	
SEACAT conductivity/temp	2322	-1.83	-1.17	At temp probe
Temperature recorder	3837	-0.59	-0.26	Thermistor end
Temperature recorder	3833	-0.78	-0.45	Thermistor end
Temperature recorder	3308	-1.33	-1.00	Thermistor end
Temperature recorder	3291	-1.83	-1.50	Thermistor end
Temperature recorder	3296	-2.33	-2.00	Thermistor end
Temperature recorder	4402	-2.83	-2.50	Thermistor end
Tension cell	94034	Base of bridle		

Distance between buoy deck and water line was .33 meters

Table 2-1-3. PACS1 South discus buoy-mounted sensors and corresponding elevations.

Parameter	Sensor ID	Elevation relative to buoy deck [meters]	Elevation relative to water line [meters]	Measurement Location
IMET	Logger 143			
Wind speed	WND 105	2.89	3.22	Prop Axis
Wind direction	WND 105	2.89	3.22	Prop Axis
Air temperature	TMP 104	1.72	2.05	End of probe
Aspirated air temp	TMP 106	1.86	2.19	End of probe
Relative humidity	HRH 110	2.31	2.64	Tip of sensor
Barometric pressure	BPR 110	2.37	2.70	Center of port
Precipitation	PRC 109	2.74	3.07	Top of funnel
Long-wave radiation	LWR 104	3.05	3.38	Base of dome
Short-wave radiation	SWR 109	3.05	3.38	Base of dome
Sea temperature	SST 005	-1.36	-1.03	End of Probe
VAWR	V707WR			
Wind speed	V707WR	2.97	3.30	Center of Cups
Wind direction	V707WR			
Air temperature	5814	1.77	2.10	End of probe
Relative humidity	V-021-001	2.17	2.50	Tip of sensor
Barometric Pressure	53235	2.39	2.72	Center of port
Long-wave radiation	27957	3.05	3.38	Base of dome
Short-wave radiation	28298	3.05	3.38	Base of dome
Sea temperature	5510	-1.36	-1.03	End of probe
Stand-alone relative humidity	006	2.41	2.74	
SEACAT conductivity/temp	143	-1.71	-1.38	At temperature probe
Floating sea surface temp	WaDaR 274		-0.05	
Temperature recorder	3835	-0.63	-0.30	Thermistor end
Temperature recorder	3699	-0.87	-0.54	Thermistor end
Temperature recorder	3701	-1.34	-1.01	Thermistor end
Temperature recorder	4492	-1.84	-1.51	Thermistor end
Temperature recorder	4489	-2.34	-2.01	Thermistor end
Temperature recorder	3764	-2.85	-2.52	Thermistor end
Tension cell	dummy cell	Base of bridle		

Distance between buoy deck and water line was .33 meters

Table 2-1-4. PACS2 South discus buoy-mounted sensors and corresponding elevations.

Parameter	Sensor ID	Elevation relative to buoy deck [meters]	Elevation relative to water line [meters]	Location
IMET				
Wind speed	WND 108	2.96	3.29	Prop Axis
Wind direction	WND 108	2.96	3.29	Prop Axis
Air temperature	TMP 108	1.76	2.09	Mid shield
Aspirated air temp	TMP005	1.76	2.09	Tip of Probe
Relative humidity	HRH 108 (26356)	2.19	2.52	Mid shield
Barometric pressure	BPR 006	2.38	2.71	Center of port
Precipitation	PRC 004	2.74	3.07	Top of funnel
Long-wave radiation	LWR 103	3.06	3.39	Base of dome
Short-wave radiation	SWR 102	3.06	3.39	Base of dome
Sea temperature	SST 003	-1.33	-1.00	End of Probe
VAWR	V706WR			
Wind speed	V706WR	2.97	3.30	Center of Cups
Wind direction	V706WR	2.71	3.04	Mid vane
Air temperature	5817	1.79	2.12	Mid Shield
Relative humidity	V-036-01	2.15	2.48	Mid Shield
Barometric pressure	45918	2.38	2.71	Center of port
Long-wave radiation	28872	3.06	3.39	Base of dome
Short-wave radiation	28416	3.06	3.39	Base of dome
Sea temperature	5539	-1.33	-1.33	End of probe
Stand-alone precipitation	003	2.72	3.05	Top of funnel
ASIMET rel.hum.	HRH 206	2.49	2.82	Mid Shield
Floating SST	WaDaR 273		-0.05	
SEACAT conduct/temp.	1882	-1.83	-1.50	At temp. probe
Temperature recorder	4228	-0.56	-0.23	Thermistor end
Temperature recorder	3274	-0.81	-0.48	Thermistor end
Temperature recorder	3271	-1.33	-1.00	Thermistor end
Temperature recorder	4486	-1.83	-1.53	Thermistor end
Temperature recorder	3830	-2.33	-2.00	Thermistor end
Temperature recorder	3834	-2.83	-2.53	Thermistor end
Tension cell	43390			

Distance between buoy deck
and water line was.33 meters

The meteorological instruments are described in detail below.

2-1-a. Vector Averaging Wind Recorder (VAWR)

One of the two meteorological units mounted on the WHOI three-meter diameter discus buoy was a VAWR, which is configured to measure wind speed, wind direction, short-wave radiation, long-wave radiation, relative humidity, barometric pressure, air temperature, and sea surface temperature. Recording on a digital cassette, the VAWR wrote data to tape every 15.0 minutes. Table 2-1-5 shows the type of sensors used for the meteorological measurements and the sampling scheme. Data from the VAWR were telemetered via satellite back to WHOI through Service Argos. The VAWR Argos transmitter has three PTT ID numbers for data transmission, one of which is used for obtaining position information. The standard temperature range typically used in the VAWR is 0 to 30°C. This range for the PACS deployments was modified to be -5° to 35°C due to the expected high temperatures. The VAWR sea surface temperature (SST) sensor was mounted on the bridle at a depth of approximately one meter. A continuous length of cable was run from the VAWR to the buoy deck and then down to the bridle mounted SST sensor via an external aluminum pipe mounted on the side of the buoy to protect the cable. This method eliminated the need for multiple bulkhead connectors which can affect the temperature reading. Details of the VAWR configuration can be found in Weller and Davis (1980).

2-1-b. Improved METeorological System (IMET)

The IMET system for the PACS WHOI discus buoys consisted of nine IMET sensor modules and one Argos transmitter module to telemeter data via satellite back to WHOI through Service Argos. Table 2-1-6 details IMET sensor specifications. The following IMET modules types were deployed on the PACS discus buoys:

1. relative humidity with temperature
2. barometric pressure
3. air temperature (R. M. Young passive shield)
4. air temperature (aspirated shield)
5. sea surface temperature
6. precipitation
7. wind speed and direction
8. short-wave radiation
9. long-wave radiation

Table 2-1-5. VAWR sensor specifications

Parameter	Sensor Type	Nominal Accuracy	Comments
Wind speed	R. M. Young 3-cup 3-cup Anemometer	+5% +/-2%	Vector - averaged
Wind direction	Integral vane w/vane follower WHOI/EG&G	+/- 1 bit 5.6°	Vector- averaged
Insolation	Pyranometer Eppley 8-48	+/-3%	Averaged of reading
Long-wave Radiation	Pyrgeometer Eppley PIR	+/- 10%	
Thermopile	PIR		Averaged
Body temp.	10K @ 25° C		Note 1
Dome temp.	10K @ 25 °C		Note 2
Relative humidity	Variable Dielectric Conductor Vaisala Humicap 0062HM	+/- 2% RH	3.515 sec. Sample Note 4
Barometric pressure	Quartz crystal Digiquartz Paroscientific Model 215, 216	+/- 0.2 mbars wind < 20 m/s	2.636 sec. Sample Note 3
Sea temperature	Thermistor Thermometrics 4K @ 25°C	+/-.005°C	Note 4
Air temperature	Thermistor Yellow Springs #44034 5K @ 25°C	+/- 0.2°C wind > 5 m/s +/-0.2 all winds	mutually ventillated " aspirated " Note 5

Notes:

1. LWR body temperature is measured during the third quarter of the recording interval for one quarter of the record time. Error associated with solar heating is not included in accuracy.
2. LWR dome temp. is measured during the fourth quarter of the record interval, for one quarter of the record time.
3. Relative humidity and barometric pressure are burst samples taken in the middle of the recording interval.
4. Sea temperature is measured during the first quarter of the recording interval, for one quarter of the record time.
5. Air temperature is measured during the second quarter of the recording internal, for one quarter of the record time.

Table 2-1-6. IMET sensor specifications

Parameter	Sensor	Nominal Accuracy
Air temperature (Static Shield)	Platinum Resistance Thermometer	+/-.25°C
Aspirated Air Temperature	Platinum Resistance Thermometer	+/-.10°C
Sea temperature	Platinum Resistance Thermometer	+/-.005°C
Relative humidity	Rotronic MP-100F	+/- 3%
Barometric pressure	Quartz crystal AIR DB-1A	+/- .5 mbar
Wind speed and	R. M. Young model 5103	-3% (speed)
Wind direction	Wind Monitor	+/- 1.5° (dir)
Short-wave radiation	Temperature Compensated Thermopile Eppley PSP	+/- 3%
Long-wave radiation	Pyrometer Eppley PIR	+/- 10%
Precipitation	R. M. Young model 50201 Self-siphoning rain gauge	+/- 10%

Notes:

The logger polls all IMET modules at one-minute intervals (takes several seconds) and then goes to low power sleep mode for the rest of the minute. Data is written to disk once per hour. The logger also monitors main battery and aspirated temperature battery voltage.

The air temperature, sea-surface temperature, barometric pressure, relative humidity, long-wave radiation and precipitation modules take a sample once per minute and then go to low power sleep mode for the rest of the minute.

The short-wave radiation module takes a sample every ten seconds and produces a running one minute average of the six most recent samples. It goes to low power sleep mode between ten second samples.

The vane on the wind module is sampled at one-second intervals and unit-vector averaged over 15 seconds. The compass is sampled every 15 seconds and the wind speed is averaged over 15 seconds. East and north current components are computed every 15 seconds.

Once a minute, the logger stores an average east and north component that is an average of the most recent four 15 second averages. In addition average speed from four 15 second averages is stored, along with the maximum and minimum speed during the previous minute, average vane computed from four, 15-second averages, and the most recent compass reading.

In addition, an IMET Argos PTT module was set for three IDs and transmits via satellite the most recent six hours of one-hour averages from the IMET modules. At the start of each hour, the previous hour's data is averaged and sent to the PTT, bumping the oldest hour's data out of the data buffer.

All IMET modules for the PACS experiment were modified for lower power consumption so that a non-rechargeable alkaline battery pack could be used in the buoy well.

The IMET system including the data logger and modules are powered off a common bank of batteries. The exception is the aspirated air temperature module and the associated fan aspirator which had its own dedicated batteries that would provide continuous operation for the first 50 to 70 days of operation.

The data logger for the system is based on an Onset Computer, Corp., model 7 Tattletale computer with hard drive which is also configured and programmed with power conservation in mind. An associated interface board ties the model 7 via individual power and RS-485 communications lines to each of the nine IMET modules including the PTT module.

2-1-c. Stand-alone Relative Humidity/Air Temperature Instrument

A self-contained relative humidity and air temperature instrument was mounted on the tower of the PACS1 discus buoys. This instrument, developed and built by members of the UOP Group, takes a single point measurement of both relative humidity and temperature at a desired record interval. The sensor used is a Rotronics relative humidity sensor, model MP-100. The relative humidity and temperature measurements are made inside a protective Gortex shield. The logger is an Onset Computer, Corp., Model 4A Tattletale, with expanded memory to 512 K. The unit is powered by its own internal battery pack. The instrument record interval was set to 3.75 minutes for the PACS experiment. Table 2-1-7 shows the type of sensors and their nominal accuracy.

Table 2-1-7. UOP Relative Humidity/Air Temperature Sensor Specifications

Parameter	Sensor	Nominal Accuracy
Relative humidity	Rotronic MP-100F	+/- 3%
Air Temperature		.05°C

2-1-d. Stand-alone Precipitation Instrument

A self-contained precipitation instrument was mounted on the tower of the PACS2 discus buoys. This instrument, developed and built by members of the UOP Group, takes a single-point measurement of rainfall at a desired record interval. The sensor used is an R. M. Young, model 050202, self-siphoning rain gauge. This sensor uses a capacitive measurement technique to measure the volume of rain water deposited inside a collection chamber. It automatically empties in about 20 seconds when the chamber is full. The output of the sensor is 0 to 5 Vdc, which represents 0 to 50 mm of rainfall in the gauge. The sensor was sampled every 3.75 minutes during the PACS2 deployment. The logger is an Onset Computer, Corp., model 4A

Tattletale, with expanded memory to 512K. The unit is powered by its own internal battery pack.

During PACS1, the IMET system on the North buoy began to experience an intermittent Argos telemetry problem. It was unclear as to whether or not the IMET system was working properly. The VAWR mounted on the same buoy provided redundant measurements for all the variables except precipitation. In order to provide some redundancy with regard to the precipitation measurement, arrangements were made with Sandra Yuter (University of Washington) to install a stand-alone precipitation instrument on the North buoy. The sensor was mounted on the North buoy during a cruise of the R/V *Ron Brown* on August 8, 1997. However, this instrument was destroyed by vandalism and did not return any data.

2-1-e. ASIMET relative humidity with temperature instrument

An ASIMET relative humidity module was mounted on both the North and South discus buoys deployed during PACS2. The ASIMET module is an improved version of the IMET module developed for the World Ocean Circulation Experiment (WOCE) program and VOS program. ASIMET modules are self-powered and internally recording. The relative humidity measurement is made with a Rotronic MP-101A sensor. The sensor is packaged in a custom housing, which is more rugged than the standard housing and with high pressure water seals. The humidity temperature probe provides analog outputs of 0 volts to 1.0 volts DC for humidity (1 to 100% rh): and 0 to 1.0 volts DC for temperature (-40° to +60°C). These signals are amplified and converted to digital in the module. One set of measurements are made every minute and calibrated via a fourth order polynomial for rh% and degrees C. The probe is placed inside a standard R. M. Young multi-plate radiation shield. Table 2-1-8 shows the type of sensors and their nominal accuracy.

Table 2-1-8. ASIMET Sensor Specifications

Parameter	Sensor	Nominal Accuracy
Relative humidity	Rotronic MP-101A	+/- 2%
Air Temperature		.05°C

2-2. Subsurface Instrumentation

A schematic of the four PACS moorings are shown in Figures 2-1-2, 2-1-3, 2-1-4, and 2-1-5 showing the depths of the subsurface instruments. Table 2-2-1 lists the PACS1 and PACS2 North sub-surface instrumentation and Table 2-2-2 lists the PACS1 and PACS2 South sub-surface instrumentation and the depths where they were deployed. For specific information on the two deployments, see the cruise reports.

The remainder of this section will describe the sub-surface instrumentation deployed during PACS .

2-2-a. PACS2 Mooring Line Tension Recorder and Buoy Acceleration

Mooring tension was measured at the base of the rigid bridle on PACS1 North and on both the PACS2 South and North buoys. A three-axis accelerometer was placed in each of the four buoy wells. The tension cell on the North buoy was an Omegadyne, Inc., model TH-LB1B(SPL), with a load range of 0 pounds to 10,000 pounds. The tension cell on the South buoy was a D. J. Instruments, model A-16012, also with a load range of 0 pounds to 10,000 pounds. Inside the well of each buoy was a three-axis accelerometer manufactured by Summit Instruments, model #34103A, which measures X, Y, and Z components. The tension and acceleration data were recorded using an Onset Computer, Corp., model 6 Tattletale, with a 40 Mega Byte hard drive attached. Tension and acceleration were sampled every 12 hours beginning at 0000 UTC and 1200 UTC at a 4 HZ rate for a period of 23 minutes. The data from a two-day period were stored in a temporary buffer where it was then written to the disk drive. A time spike was applied to the tension cells by pulling on the bridle bail with an aircraft strap.

2-2-b. SEACAT Conductivity and Temperature Recorder

The model SBE 16 SEACAT is designed to measure and record temperature and conductivity at high levels of accuracy while deployed in a moored application. Powered by internal batteries, a SEACAT is capable of recording data for periods of a year or more. Data is acquired at intervals set by the user. This interval can be changed at up to nine, pre-determined dates. An internal back-up battery supports memory and the real time clock in the event of failure or exhaustion of the main battery supply. Communication with the SEACAT is over a three-wire RS-232 link. The SEACAT is capable of storing a total of 64,754 samples. A sample rate of 450 seconds was used on the PACS SEACATs. The shallowest SEACAT was mounted directly to the bridle of each of the WHOI discus buoys. The others were mounted on in-line

Table 2-2-1. PACS1 and PACS2 North Subsurface Instrumentation

Depth	PACS1	PACS2
Surface	WaDaR-275	WaDaR 272
.25	T-3263	T-3837
.50	T-4491	T-3833
1.0	T-4485	T-3308
1.0	VAWR SST	VAWR SST
1.0	IMET	IMET SST 106
1.5	T-3258	T-3291
1.5	SEACAT-994(1.8m)	SEACAT 2322
2.0	T-3838 (1.4m)	T-3296
2.5	T-3704	T-4402
3.5	MTR-3240	MTR-3241
5.0	VM-016	VM-017
7.5	T-3259	SEACAT 1881
10.0	VM-020	VM-044
12.5	SEACAT-928	T-4488
15.0	VM-014	VM-055
17.5	T-4481	SEACAT 141
20.0	VM-015	VM-010
22.5	SEACAT-995	T-3508
25.0	T-3703	T-4493
27.5	RainGauge-002(29.0m)	SEACAT 1875
30.0	VM-037	VM-028
32.5	SEACAT-992	
35.0	T-3761	T-2535
37.5		SEACAT 1873
40.0	VM-013	VM-027
45.0	T-3309	T-2541
47.5		SEACAT 927
50.0	VM-033	VM-002
60.0	T-4495	T-2537
65.0		SEACAT 1877
70.0	VM-031	VM-012
80.0	MicroCAT-09	MicroCAT 011
90.0	VM-026	VM-052
100.0	T-4487	T-3701
110.0	VM-019	VM-001
120.0		-----------
130.0		-----------
150.0	T-3662	T-3764
200.0	T-3839	T-3835

Legend

T-#### = Brancker Temp Recorder
SEACAT #### = SEACAT Conductivity and Temp Recorder
MTR-### = MiniatureTemperature Recorder
WaDaR-### = WaDaR Temperature Recorder
MicroCAT-### = MicroCAT Conductivity and Temp Recorder
VM-### = Vector Measuring CM
Sherman CM ## = SIO acoustic doppler CM
Bio-Optical Pkg = WHOI bio-optical package

Table 2-2-2. PACS1 and PACS2 South 2 Subsurface Instrumentation

Depth	PACS1	PACS2
Surface	WaDaR-274	WaDaR-273
.25	T-3835	T-4228
.50	T-3699	T-3274
1.0	T-3701	T-3271
1.0	VAWR -707	VAWR SST
1.0	IMET SST5	IMET-003
1.5	T-4492	T-4486
1.5	SEACAT-143(1.71m)	SEACAT 1882
2.0	T-4489	T-3830
2.5	T-3764	T-3834
3.5	MTR-3243	MTR-3242
5.0	VM-009	VM-045
7.5	T-3836	SEACAT 1874
10.0	VM-011	VM-023
12.5	SEACAT-993	T-3763
15.0	VM-056	VM-041
17.5	T-3265	SEACAT 1878
20.0	VM-038	VM-043
22.5	SEACAT-991	T-3506
25.0	T-4494	T-3507
27.5	ACH-0126	Bio-Optical Pkg
30.0	VM-039	VM-022
32.5	SEACAT-929	
35.0	T-3279	T-3301
37.5		SEACAT 1876
40.0	VM-025	VM-051
45.0	T-4483	T-3831
47.5		SEACAT 142
50.0	VM-032	VM-053
60.0	T-3667	T-3702
65.0		SEACAT 1880
70.0	VM-018	VM-034
80.0	MicroCAT-010	MicroCAT 008
90.0	VM-008	VM-030
100.0	T-3283	T-3299
110.0	VM-021	VM-040
120.0	Sherman CM001	Sherman CM 001
130.0	FSI CM-1428A	VM-201
150.0	T-4482	T-2533
200.0	T-3762	T-2536

Legend

T-#### = Brancker Temp Recorder
SEACAT #### = SEACAT Conductivity and Temp Recorder
MTR-### = MiniatureTemp Recorder
WaDaR-### = WaDaR Temperature Recorder
Bio-Optical Pkg = WHOI bio-optical package
VM-### = Vector Measuring CM
Sherman CM ## = SIO acoustic doppler CM
MicroCAT-### = MicroCAT Conductivity and temp recorder

tension bars and deployed at various depths throughout the moorings. Shaft anodes were secured to the in-line tension bars to reduce the potential for electrolysis.

2-2-c. MicroCAT Conductivity and Temperature Recorder

The Sea-Bird MicroCAT, model SBE37, is a high-accuracy, conductivity and temperature recorder with internal battery and memory, designed for long term mooring deployments. It includes a standard serial interface to communicate with a PC. Its recorded data are stored in non-volatile FLASH memory. The temperature range of the instrument is -5° to +35°C and the conductivity range is 0 to 6 Siemens/meter. The pressure housing is made of titanium and is rated for 7,000 meters. The conductivity cell is protected from bio-fouling by the placement of anti-foulant cylinders at each end of the conductivity cell tube. The MicroCAT is capable of storing 120,000 samples of temperature, conductivity and time. The sampling interval of the PACS1 and PACS2 MicroCAT was 225 seconds. Both the PACS2 North and South moorings had a MicroCAT placed at 80 meters. The MicroCATs deployed on the PACS1 and PACS2 WHOI moorings were purchased with two titanium tabs welded to the pressure case so that the instrument could be bolted to a titanium strength member. The strength member was placed in line on the mooring.

2-2-d. Brancker Temperature Recorders

The Brancker temperature recorders are self-recording, single-point temperature loggers. The operating temperature range for this instrument is -2° to 34°C. They have an internal battery and the capability of logging 28,000 samples. A PC is used to communicate with the Brancker via serial cable for instrument set-up and data download. The PACS1 and PACS2 Branckers were set to record data every 30 minutes.

A total of 60 Brancker temperature loggers were deployed on the discus moorings, with 15 on each of the buoys. Six were attached to the buoy in a near-surface temperature string, with depths ranging from .25 meters to 2.5 meters. The other nine Branckers on each mooring were dispersed at depths ranging from 7.5 meters to 200 meters.

2-2-e. Miniature Temperature Recorder

A Pacific Marine Environmental Lab (PMEL), Miniature Temperature Recorder (MTR) was mounted in line at a depth of 3.5 meters on each of the WHOI moorings. The MTR is a single-point temperature logger. System timing and sampling are controlled by an internal microprocessor. It has an internal 9-volt battery which will power the MTR for periods of greater than one year. Communication is through a serial cable using a PC. The data, as raw counts, are stored along with system software in battery backed RAM. The MTR has the capability of storing 56,800 samples of temperature. The MTRs were set up for PACS2 to sample at a rate of 450 seconds.

2-2-f. WaDaR Temperature Recorder

All of the PACS surface buoys were outfitted with a surface-following temperature logger in order to measure sea-surface temperature. The temperature logger selected for this application was a WaDaR model TL, temperature logger, manufactured by TSKA, Inc. The instrument is self-contained, with batteries, memory and a microprocessor directing operations. A PC is used to communicate with the WaDaR in order to set up the instrument for recording and to download the data. The WaDaR will record up to 65,520 temperature measurements in a single deployment. For the PACS experiment the record rate was set to 450 seconds. The WaDaR has a temperature range of -3° to +35°C. The pressure case is made of titanium and is rated for full-ocean depth. The WaDaR was deployed in a molded syntactic foam float designed to follow the ocean surface. The float ran up and down along three stainless guide posts that were attached to the up-wind side (side opposite wind vane) of the discus buoy.

It was noted prior to the recovery of the PACS1 South buoy and PACS2 North and South buoys that the float was freely moving up and down with each passing wave. The stainless rods were free of any growth, presumably because of the wiping action of the float. The float that was deployed on PACS1 North buoy was recovered with the sensor out of the water and the float stuck in the up position. At least one of the guide rods on the North buoy was bent preventing the float from moving freely. It is suspected that the damage to the rods was caused by a vessel that may have tied up to the buoy. The floats deployed to the PACS2 buoys were observed to be moving freely following their deployment.

2-2-g. WHOI Vector Measuring Current Meters (VMCMs)

TheVMCM has two orthogonal cosine response propeller sensors that measure the components of horizontal current velocity parallel to the axles of the two propeller sensors. The orientation of the instrument relative to magnetic north is determined by a flux gate compass. East and north components of velocity are computed, averaged and then stored on cassette magnetic tape. Temperature was also recorded using a thermistor mounted in a fast response pod, which was mounted on the top end cap of the VMCM. The VMCMs were set to record data every 7.50 minutes. A total of 40 VMCMs were deployed on the WHOI surface moorings, ten on each mooring, at various depths ranging from 5 meters to 110 meters. All of the WHOI VMCMs had a compass check done at the dock prior to departure to verify that the compass was not damaged in transport. A description of how each parameter in the VMCM is sampled appears in Trask *et al.*, 1998.

A VMCM with new electronics and the standard orthogonal propeller sensor was deployed at 130 meters on the PACS2 South mooring. It is the first deployment of a WHOI-upgraded instrument and is intended as a test of the new electronics. Low-power microcontroller technology is the heart of the new VMCM. The primary sub-unit in the VMCM is a vector measuring front end, consisting of rotor and compass hardware interface and a low-power microcontroller to sample these. The instrument deployed in PACS2 has a Precision Navigation, Inc., TCM2-LP, compass which is linked via RS-232 serial interface to a PIC controller. The TCM2 is a high-performance, low-power electronic compass sensor that outputs compass heading, pitch, and roll readings via electronic interface to the host system. Data are stored on a PCMCIA "flash card" rather than cassette tape, which is standard in the older units. A standard pressure case and load cage were used for the PACS2 deployment.

2-2-h. FSI Current Meter

A Falmouth Scientific, Inc., (FSI) acoustic current meter (ACM) (s/n 1428 a) was deployed at a depth of 130 meters on the PACS1 South mooring. The FSI current meter "measures velocity along four acoustic paths, three orthogonal magnetic vectors and two orthogonal gravity vectors (tilt) from which it calculates velocity relative to the earth" (FSI 3D-ACM Operating Instructions). In addition to east, north, and vertical components of current velocity, the instrument also recorded temperature, tilt, current direction and time. The instrument was set to record once every 15 minutes, which corresponds to an average measurement of 890 seconds. The remaining 10 seconds were necessary for the instrument to perform the various current calculations and store them in memory without corrupting the current measurement.

Upon recovery of the FSI 3D-ACM, three of the instrument's four fingers which house the acoustic transducers were broken off and missing. Based on a preliminary look at the data, the manufacturer suspects that the loss of the first finger occurred on May 27, 1997, approximately one month after deployment. The cause of the breakage is unknown. The instrument collected a complete record of temperature and tilt data.

Tests conducted by Falmouth Scientific, Inc., concluded that 55 pounds of force are required perpendicular to the tip of the finger for a fracture to occur. The fracture line on the tested fingers was identical to that of the instrument deployed on the PACS1 mooring, which indicates that the force was applied from the surface toward the sea floor. The manufacturer hypothesizes that the first finger was broken as a result of the instrument coming in contact with a fish of sufficient size to exceed the structural strength of the finger. Downward motion due to the heave of the surface buoy coupled with fish contact may have exceeded the breaking strength of the finger assembly.

2-2-i. Sherman Current Meter

This instrument, developed by Russ Davis and Jeff Sherman at SIO, is an acoustic doppler current meter. Two orthogonal acoustic sensors point outward in the horizontal plane at the top of the instrument. Each sensor samples the along-beam velocity in a range bin away from the pressure case, thus avoiding eddies and other flow disturbance near the pressure case and supporting cage. A Sherman current meter was deployed on both the PACS1 and PACS2 South moorings at a depth of 120 meters. During PACS1 it was bracketed by a VMCM and FSI acoustic current meter at 110 and 130 meters respectively. During PACS2 it was bracketed by a standard VMCM at 110 meters and a VMCM with new electronics at 130 meters depth. No data were recorded during PACS1 due to a loose connector. Only temperature data were recorded on PACS2.

2-2-j. Chlorophyll Absorption Meter

A WET Labs Chlorophyll Absorption Meter (CHLAM), model number 9510005, serial number ACH0126, was placed on the PACS1 South discus mooring at a depth of 27.5 meters. The CHLAM was mounted on a frame that fit inside a standard 3/4" VMCM cage. A Sea-Bird pump draws water through the CHLAM and a brominating canister. Between samples, the bromide diffuses through the system to reduce bio-fouling. Data are stored to a WET Labs MPAK data logger. The CHLAM/MPAK records a reference and signal from three optical wavelengths, 650, 676 and 712 nano-meters (nm) and an internal temperature. The sample interval rate was two hours. At each sample, the pump was turned on for ten seconds to flush the system then ten seconds of sampling with the ten-second average of signal and reference stored in the MPAK. The complete system was powered by two, 10 D-cell alkaline battery packs.

Upon recovery communications with the MPAK could not be established because the battery packs were both fully depleted. Several attempts to communicate with the instrument were unsuccessful. The instrument was returned to the manufacturer where they were able to recover the data from the logger. The instrument collected useful data until approximately 15 July 1997, when the biofoulant was completely dissolved.

2-2-k. Bio-optical Package

A bio-optical package developed by Paul Fucile (WHOI) was deployed on the PACS2 South mooring at a depth of 27.5 meters. The moored bio-optical package included: a WET Labs., WETStar Miniature Chlorophyll Flourometer; a Sea Tech, Inc., 25 cm. transmissometer; a Sea-Bird conductivity cell; a Sea-Bird temperature sensor; a LI-COR®, spherical Photosynthetically Active Radiation (PAR) sensor; as well as an upwelling PAR sensor, also by LI-COR®; and a Seapoint Sensors, Inc., turbidity meter. The instrument was controlled by Onset Computer, Corp., tattletale model 4A; and the data are stored on non-volatile PCMCIA in DOS readable files. Thus, the data can be read by a PC with a PCMCIA slot or a resident program in the logger which permits serial downloading of the data. Internal batteries provide power for deployments of up to one year. For the PACS2 deployment the sampling interval was set at 3.75 minutes. Biofouling and instrument problems limited the period of useful data return to 2 weeks.

2-2-1. Acoustic Rain Gauge

An acoustic rain gauge from Jeff Nystuen at the Applied Physics Laboratory at the University of Washington was deployed on the PACS1 North mooring at a depth of 29 meters. This instrument listens to ambient noise with a hydrophone. Rain falling on the sea surface produces noise at certain frequencies which are sampled by this instrument. Upon recovery, the instrument was entangled in fishing net. It appears that when attempts were made to pull the net away from the North mooring, the hydrophone guard cage was damaged. The hydrophone and instrument did not appear to have sustained any damage. Evaluation of the data collected by the acoustic rain gauge indicated that the instrument had an intermittent electronics problem, and, as a result, collected data for only portions of two days while on the mooring.

Section 3: Data Processing and Return

This section presents a summary of the data return rates, data processing and quality control. It is broken down into two subsections. The first will cover the surface meteorological data and air-sea fluxes. The second will cover all the subsurface data.

3-1. Meteorological data processing.

The raw VAWR data were processed using the WHOI UOP software package (Prada, 1992). The raw IMET, ASIMET and Stand-Alone data were processed using IDL programming language scripts developed by WHOI UOP. Pre-deployment calibrations were applied to each instrument initially and post-deployment calibrations were only used when they yielded better agreement during inter-comparisons with other sensors. All calibrated data were converted to EPIC-compliant Net CDF files (Denbo and Zhu, 1993; Rew *et al* 1993). The raw wind directions were rotated by 9.46° and 9.39° for NORTH and SOUTH, respectively, to correct for the local magnetic deviation. After initial processing, qualitative checks were performed on the data to identify sensor problems such as spikes, drop-outs or gross errors.

The meteorological data from the IMET and VAWR are evaluated by using the redundant measurements and pre-deployment/post-deployment calibrations. This section summarizes in writing the evaluation of meteorological parameters from each for the four buoy deployments. Based on this evaluation process a composite time series of meteorological data is made by choosing the best available data record for each variable. No empirical adjustments have been applied at this time to the data to improve agreement among these collocated sensors. All statistics, plots and air-sea fluxes shown in Sections 4 and 5 are derived from this composite time series.

Written summaries for each buoy and each deployment, describing the condition of the sensors and an evaluation of the data quality follow in Tables 3-1-1, 2, 3,4. Data return for the meteorological instruments is provided in Figures 3-1-1, 2, 3 and 4 showing the percentage of time that a particular instrument was returning good data for both deployments. A summary of the parameters and instrument chosen for the composite time series is given in Section 3-1-a. Section 3-3 includes a description of the processing used to calculate a time series of the air-sea exchange of fresh water, heat and momentum from the composite time series.

Table 3-1-1. PACS I North Meteorological Summary

Data Return

VAWR and IMET data loggers provided a complete data set.

Wind Speed and Wind Direction

VAWR wind speed intermittently goes to near zero at the end of the deployment (9/23/97 to the end). IMET looks good. VAWR over-speeding and/or IMET under-speeding is evident in scatter plot. The VAWR is higher than the IMET by 5.3%.

VAWR wind direction died due to a broken vane around 9/23/97. IMET wind directions look fine, although no comparison is possible after 9/23/97. Check against turnaround cruise shipboard wind directions if possible. Prior to 9/23/97, the mean bias is only 2.1 degrees with a standard deviation of the difference of 8.1 degrees.

Air Temperature

Mean difference between VAWR and IMET is -.06 °C with a standard deviation of the differences of 0.155 °C. These statistics indicate good agreement considering the ~0.2 °C accuracy of the air temperature measurements. Radiative heating errors were detected in all of the air temperature measurements.

The mean errors are small (~0.2 °C), but in our experience, the instantaneous errors may much larger. There has been no adjustment to account for these errors.

Relative Humidity

The IMET RH died on 10/2/97 but came back alive with intermittent dropouts on 10/24. It died again for good on 11/24/97. VAWR has a full record. Prior to IMET problems, there was a time dependent linear drift in the difference between the two sensors. The Standalone relative humidity increases abruptly around 10 June 1997 by 5-6% RH. From this date to the end of the deployment, the Standalone measureds relative humidities that were higher than either the VAWR or IMET. From comparisons with the Standalone, it appears that the VAWR is the sensor with the drift in it. Despite this drift, the VAWR is in better agreement with the Standalone. Because of its better quality and full record, the VAWR is the 'best' PACS I North RH time series.

Specific Humidity

Because of the step error in the Standalone RH around 10 June 1997, the specific humidity is calculated from the VAWR relative humidity and IMET air temperature and barometric pressure.

Barometric Pressure

Both IMET and VAWR data look good. There is a linear drift with time in the difference between the two sensors which is large (~0.8 mbar) at deployment and small (~0.1 mbar) at recovery.

Short-wave Radiation

Both VAWR and IMET data look good. The IMET is 7.25% higher than the VAWR, though. IMET short-wave was reduced by 5.7% per R. Payne (3/3/98) based on Eppley post-calibration. The new IMET time series is now 1.64% higher than the VAWR.

Long-wave Radiation

Both sensors have good data for the entire deployment. Both the mean bias and standard deviation of the differences are less than 10 W/m^2, indicating good agreement. The VAWR is consistently higher than the IMET, however, by an average 5 W/m^2.

Table 3-1-2. PACS 2 North Meteorological Summary

Data Return

The IMET has short record and ends in late April, 1998. There for the VAWR supplied the complete data record. Comparisons between limited IMET data and VAWR data are used to evaluate the VAWR record.

Wind Speed and Direction

Agreement before that date is only fair with a mean bias of 0.44 m/s (indicating VAWR is higher than IMET) and a standard deviation of the differences of 0.58 m/s. The VAWR is consistently rotated east of north relative to the IMET by a mean bias of 4.0 degrees.

Barometric Pressure

Both VAWR and IMET records are short. The VAWR record ends in early February, 1998 while the IMET ends in late April, 1998. Agreement before mid February is fair but consistent with the IMET higher than the VAWR by an average 0.49 mbar. The accuracy of the sensors is around 0.2 mbar.

Air Temperature

The IMET air temperature, RH air temperature and aspirated air temperature all have short records ending in late April, 1998. Both the VAWR and Standalone air temperatures have full records. Agreement between the IMET and the IMET aspirated temperature is excellent with the nighttime IMET air temperature only an average 0.009 degrees higher than the aspirated air temperature. The standalone is 0.41 and 0.40 degrees higher than the IMET and nighttime aspirated air temperature, respectively. The VAWR is 0.08 and 0.03 degrees higher than the IMET and nighttime aspirated air temperature, respectively. No radiative heating correction has been applied.

Relative Humidity

The IMET has a short record that ends in late April, 1998 while the VAWR and Standalone have full records. The IMET appears to start to drift around the beginning of March, 1998. Agreement between the IMET and both the VAWR and Standalone before this period is good. The Standalone appears to drift toward higher values and saturates at 100% RH after mid May, 1998 when compared to the VAWR.

Short-wave Radiation

The IMET record ends in late April, 1998. Agreement before that date is fair with the IMET about 6% higher than the VAWR with the pre-calibration. However, post-calibration for IMET short-wave was approximately 5% and a comparison of VAWR short-wave from a clear-sky day just prior to the end of PACS 1 with a clear-sky day at the start of PACS 2 shows excellent agreement.

Long-wave Radiation

IMET record ends in late April, 1998. Agreement before that date is good with the VAWR only an average 3.4 W/m^2 higher than the IMET.

Table 3-1-3. PACS I South Meteorological Summary

Data Return

VAWR had intermittent problems in both wind speed and direction and there is evidence that these problems were also in the other variables, suggesting that the logger was the culprit. There were severe timing problems, which provides further evidence that the logger failed occasionally. The IMET data logger provided a complete time series.

Wind Speed and Wind Direction

Despite these problems, the VAWR winds look good from mid July to mid-November, 1997. The IMET winds look good. VAWR winds were about 4.3% higher than the IMET wind speeds. The VAWR wind directions look good from mid July to mid-November, 1997, then failed intermittently at other periods. The IMET wind directions look good. When working, the agreement appears good, with a mean bias of -0.7 degrees and a standard deviation of the difference of 9.1 degrees for the entire deployment.

Air Temperature

The VAWR and IMET air temperatures agreed well. The VAWR was consistently higher, though. The mean bias was 0.055 degrees while the standard deviation of the difference was 0.14 degrees.

Relative Humidity

The VAWR and IMET relative humidity agreed well. The VAWR was consistently higher, though. The mean bias was 1.83% and the standard deviation of the difference was 1.13%. Given the accuracy of ~2-3% RH, these statistics indicate good agreement. There appears to be a slight linear drift in time in the difference time series, starting at about 0.5% at deployment and ending at around 3% at recovery. The Standalone was consistently higher than either the VAWR or IMET, but agreed slightly better with the VAWR. The Standalone increased abruptly by ~4% RH in mid-October 1997. Because of the step increase in the Standalone in mid-October 1997, the specific humidity is calculated instead from the IMET relative humidity, air temperature and barometric pressure.

Barometric Pressure

The VAWR and IMET barometric pressures agreed well. The VAWR was consistently lower than the IMET, with a mean bias of 0.25 mbar and a standard deviation of the difference of 0.14 mbar. The mean difference is slightly higher than the accuracy of the VAWR (~0.2 mbar) but within the accuracy of the IMET (~0.5 mbar). No trend in the differences was detected.

Short-wave Radiation

The IMET short-wave radiation was 6.2% higher than the VAWR. Condensation was observed on the inside of the VAWR pyranometer dome which suggests that this measurement may have problems. These results are almost identical to the PACS I North buoy short-wave comparisons, though, where no condensation on the VAWR dome was observed. The IMET incoming short-wave was reduced by 4.1% per R. Payne based on Eppley post-calibration of the IMET pyranometer (3/9/98). The IMET short-wave is now 2.3% higher than the VAWR.

Long-wave Radiation

The IMET and VAWR long-wave radiation agreed well. The mean bias was 2.5 W/m^2 and the standard deviation of the differences was only 6.2 W/m^2.

Table 3-1-4. PACS 2 South Meteorological Summary

Data Return
VAWR and IMET data loggers provided a complete data set.

Wind Speed and Wind Direction

VAWR rotors started to die in late January and finally died around the beginning of February, 1998. Agreement with the IMET before late January looks good. Due to the condition of the IMET wind sensor (bearings were missing), the wind speeds toward the end of the deployment are suspect. It is not known exactly when the bearing fell out. A post-deployment calibration of the unit without the bearings indicated that the winds may be 10-20% too low. Comparisons ECMWF model wind data does not indicate any change in time between model wind speeds, so perhaps no correction is needed.

The IMET wind direction is noisy at times from deployment until mid May, 1998 and diverges from the VAWR in late June. Comparisons of VAWR with ECMWF wind directions are consistent with the PACS 1 results indicating VAWR vane was functioning correctly.

Barometric Pressure

The IMET barometric pressure is an average 3.5 mbar higher than the VAWR and the difference between the IMET and VAWR drifts in time from near 0.5 mbar at deployment to near 0.3 mbar at recovery. Drift in time may be an artifact since barometric pressure generally increases over the life of the mooring and the scatter plot shows a very tight linear relationship.

Air Temperature

Using both daytime and nighttime values, the VAWR is an average 0.06 degrees higher than the IMET. Using only nighttime values, the VAWR is 0.07 degrees lower than the aspirated temperature and the IMET is 0.12 degrees lower than the aspirated temperature. The scatter plot of the nighttime IMET versus aspirated temperature and the histogram of the differences indicates that differences are not random about the mean difference. This suggests that in addition to being the lowest of the three measurements, there may be some other problem with the IMET air temperature.

Relative Humidity

The VAWR is an average 3.1% RH higher than the IMET while it is an average 5.0% RH higher than the Standalone. The IMET, however, is only an average 1.6% RH higher than the Standalone. Temporal drifts are apparent in all of the difference plots, but these seem small.

Short-wave Radiation

The IMET short-wave sensor has a serious temporal drift in the nighttime values from near 0 W/m^2 at deployment to near 40 W/m^2 at recovery.

Long-wave Radiation

Agreement between the VAWR and IMET is good with the VAWR slightly higher than the IMET by an average 4.5 W/m^2. IMET appears to be more noisy than the VAWR from February to May of 1998.

Surface Temperature

The IMET is consistently 0.025 degrees higher than the VAWR, but other than the bias, the agreement is excellent (r = 0.999).

Figure 3-1-3. PACS1 North IMET and VAWR Data Return

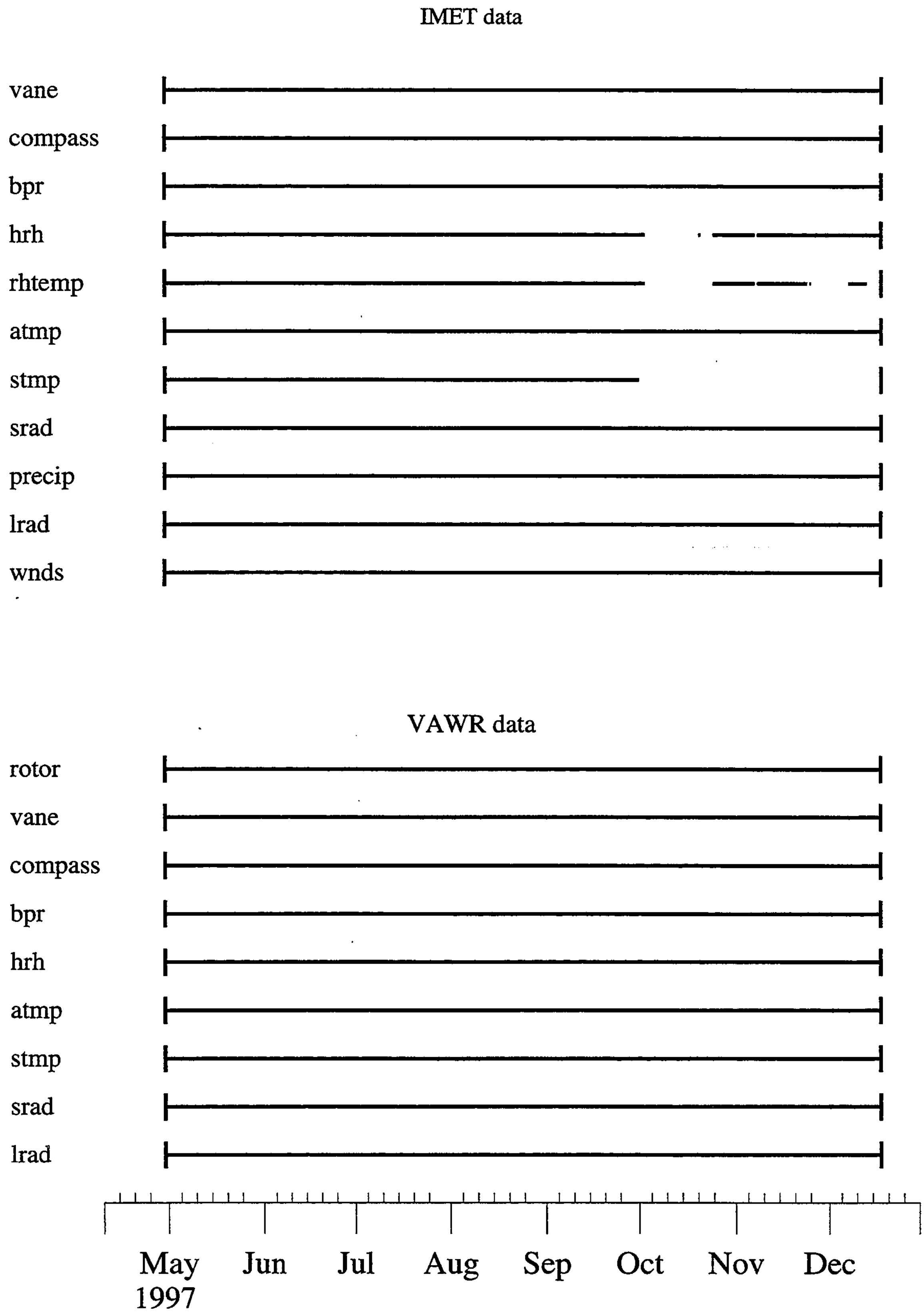


Figure 3-1-4. PACS2 North IMET and VAWR Data Return

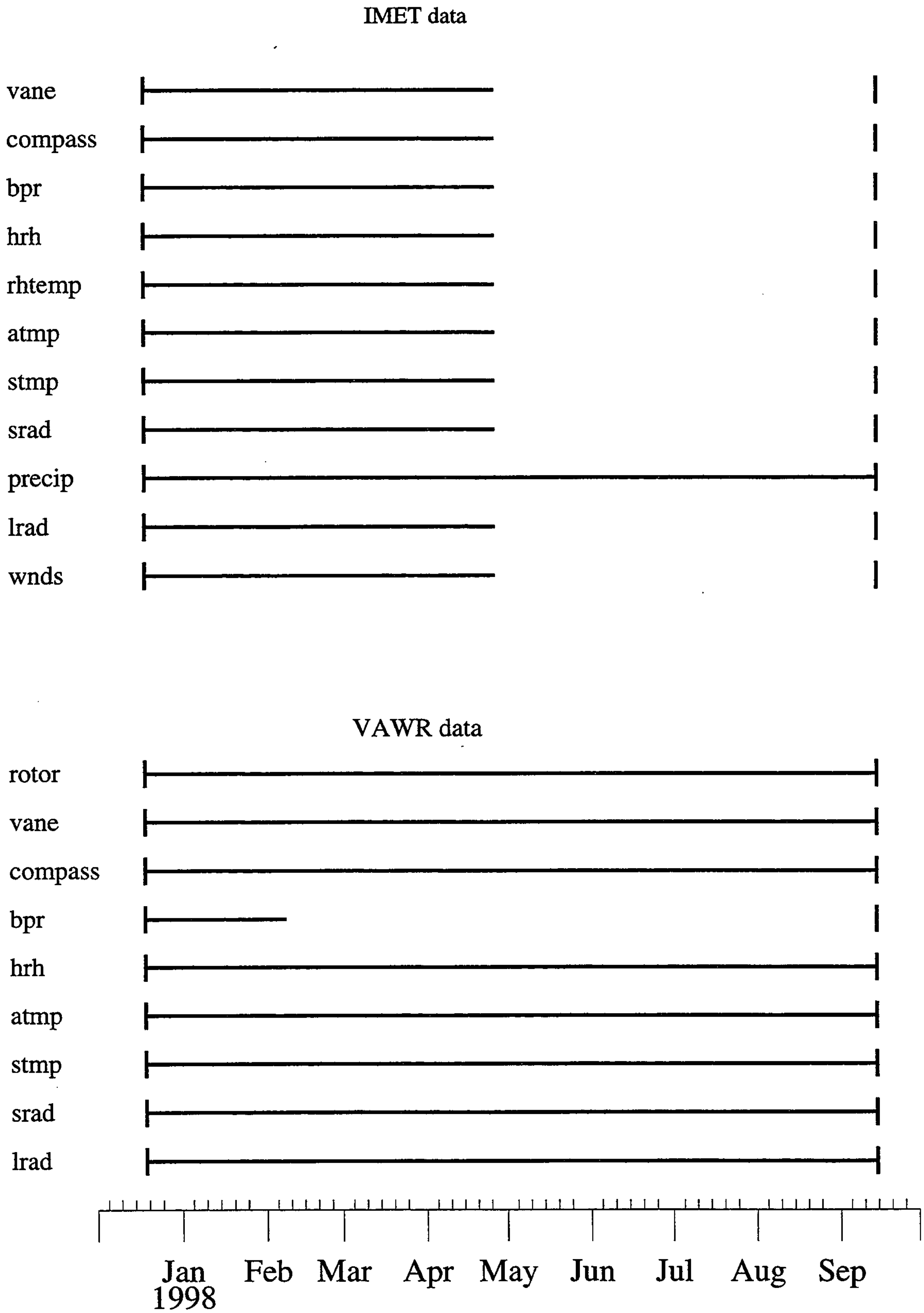


Figure 3-1-5. PACS1 South IMET and VAWR Data Return

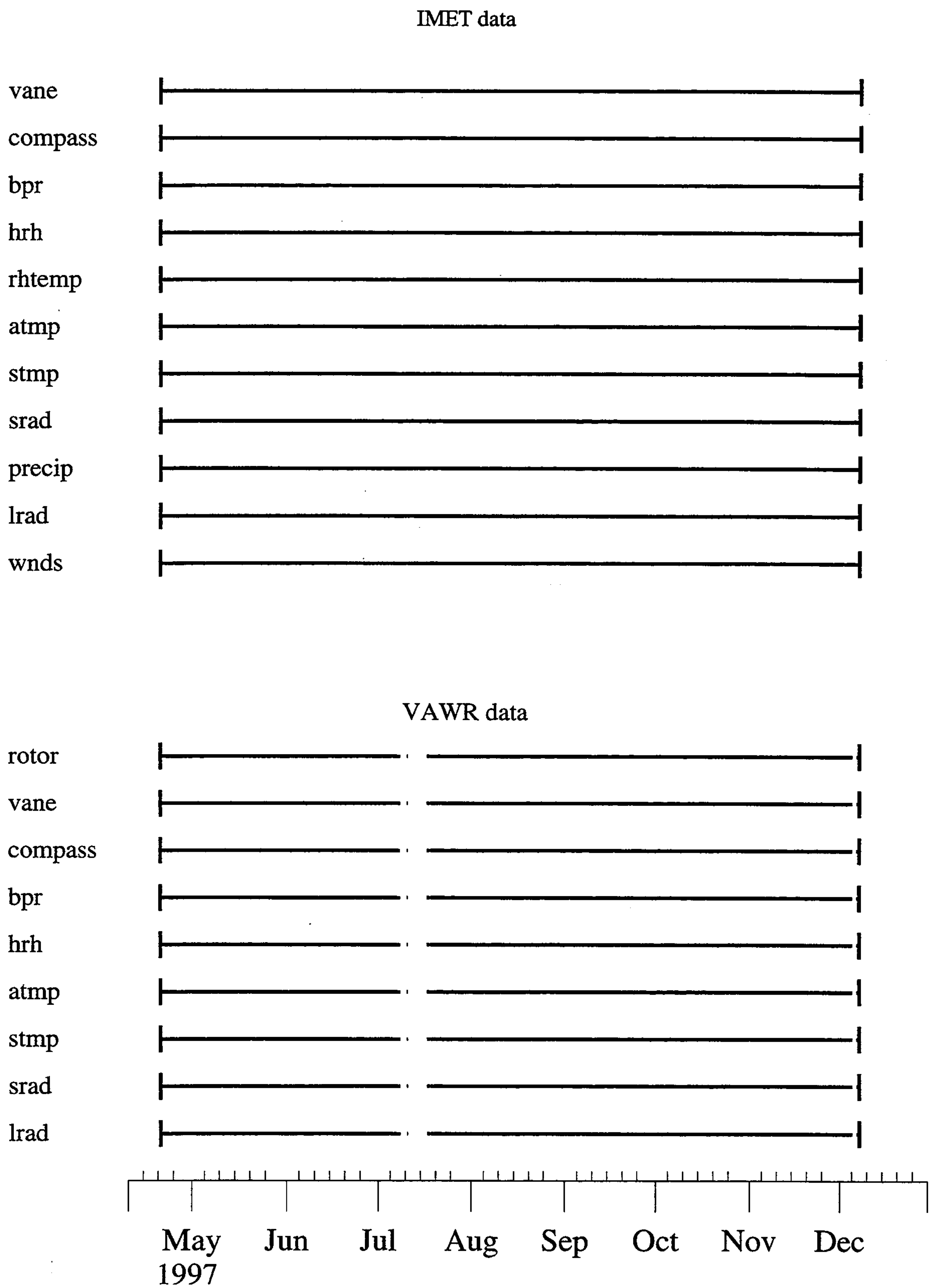
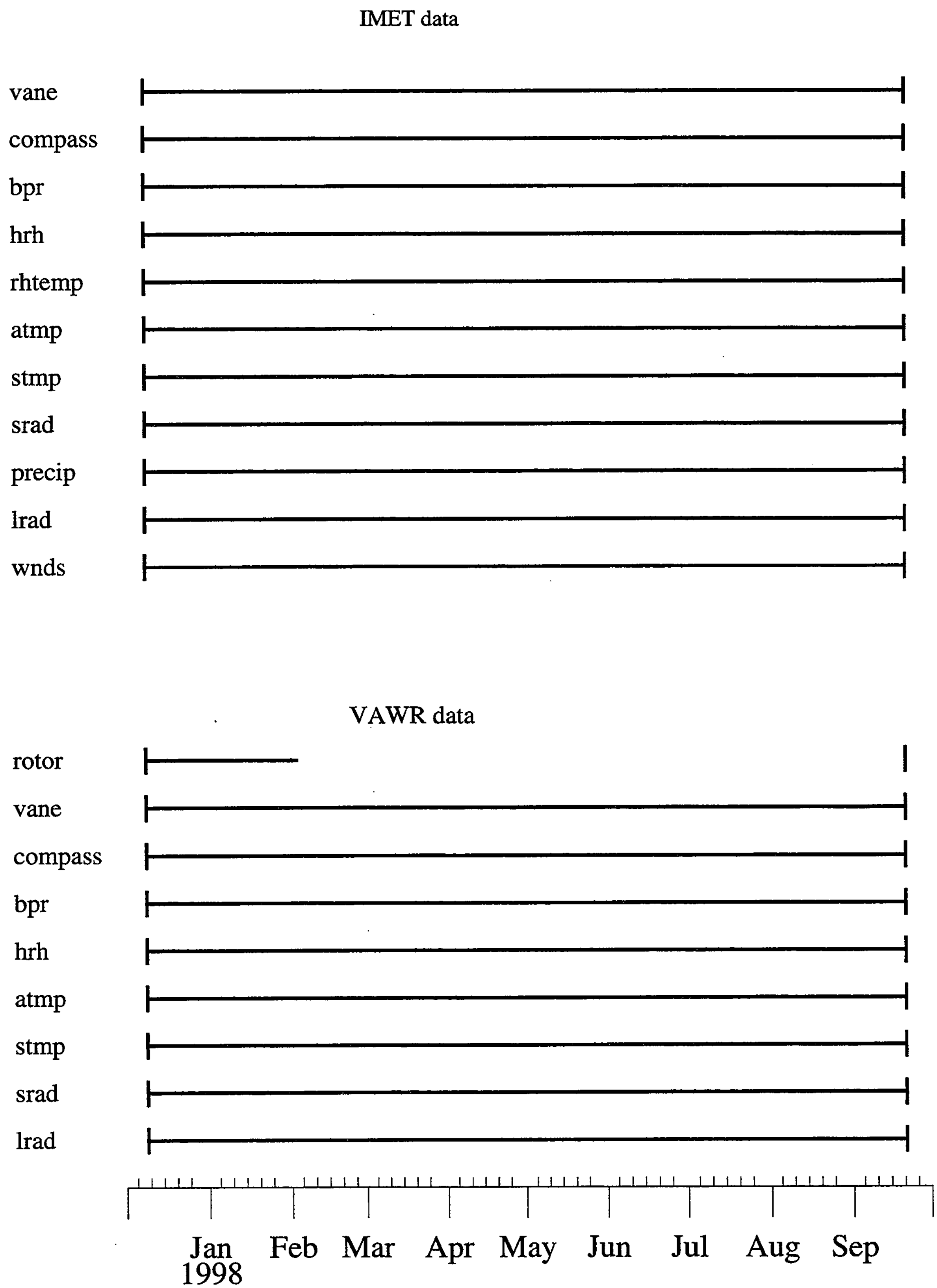


Figure 3-1-6. PACS2 South IMET and VAWR Data Return



3-1-a. Composite Meteorological Time Series.

Based on the evaluations summarized in the previous section, a preliminary composite time series was put together using the best available meteorological parameters. A summary of the parameters used in the time series is presented in Tables 3-1-a1 and 3-1-a2. A time base of 15 minute averages is used in this composite. No biases or offsets have been applied. We have used pre-deployment calibrations for all data except for the IMET short-wave data from PACS1 North and South which used the post-deployment calibrations as noted previously. This is the time series used in the analysis presented in Sections 4 and 5.

The basic sample/averaging interval for the IMET and ASIMET instrumentation is one minute. The sample interval for the Stand-Alone humidity and precipitation instruments is 3.75 minutes. The sample/averaging interval for the VAWR is 7.5 minutes. Each time series was averaged to a common 15 minute time base. The IMET and VAWR provide both vector averaged wind speeds and a scalar averaged wind speed over 1 and 7.5 minutes respectively. The vector components and the scalar wind speed were averaged to provide a vector average wind speed and a true scalar average wind speed on the 15 minute time base. Note that the magnitude of the vector averaged winds will always be equal to or less than the scalar averaged wind speeds. The scalar winds may be useful for studies of mesoscale enhancement and gustiness parameterizations. However, the 15 minute vector winds are used in the air-sea flux calculations. Note that vector winds are given in oceanographic convention: the vector points in the direction towards which the air is moving.

We have included in the composite time series a surface temperature located at either 0.25 or 0.5m. This is the sea surface temperature used in the flux calculations. The file also includes a "bulk" sea temperature from a depth of 5.0 or 7.5m. This may be useful for examining the diurnal warm layer variability.

The near surface currents are also included in the file with the composite meteorological data. These measurements come from the shallowest functioning current meter record from each mooring at a depth of 5 or 10m. The surface wind speed relative to this surface current is used in the air-sea flux calculation. This composite time series is our best attempt at quality control of this data to date and we believe them to be of high quality. However, there are a still some analysis and processing that would provide some enhancements to this data set and will be done in the future releases of the data. For example, although several weeks of aspirated air temperature data were collected on each buoy, we have not yet attempted to quantify radiative heating errors in the naturally ventilated air temperature sensors. This heating error has been documented and a protocol for correcting it has been outlined by Anderson and

Table 3-1-a1. PACS NORTH Composite Meteorological Time Series Data Sources.

	PACS 1		PACS 2	
Variable	Instrument	Height (m)	Instrument	Height (m)
Wind speed	IMET	3.25	VAWR	3.30
Wind direction	IMET	3.25	VAWR	3.30
Air Temperature	IMET	2.00	VAWR	2.15
Relative Humidity	VAWR	2.50	VAWR	2.55
Barometric Pressure [a]	IMET	2.75	IMET[a]	2.75
Short-wave Radiation	IMET	3.40	VAWR	3.40
Long-wave Radiation	IMET	3.40	VAWR	3.40
Sea Surface Temperature	TPOD # 3263	(0.25)	TPOD # 3833	(0.5)
Bulk Ocean Temperature	VMCM # 0016	(5.00)	SEACAT # 1881	(10.00)
Surface Salinity	SEACAT # 9944	(1.50)	SEACAT # 2322	(1.50)
Surface Current	VMCM # 0009	(5.00)	VMCM # 0044	(7.50)
Precipitation	IMET	3.10	Stand-Alone	2.75

[a] Barometric Pressure data ends 4/1/98.

Table 3-1-a2. PACS SOUTH Composite Meteorological Time Series Data Sources.

	PACS 1		PACS 2	
Variable	Instrument	Height (m)	Instrument	Height (m)
Wind speed	IMET	3.25	IMET	3.25
Wind direction	IMET	3.25	IMET (until 6/15/98) VAWR (after 6/15/98)	3.25 3.30
Air Temperature	IMET	2.00	VAWR	2.15
Relative Humidity	IMET	2.65	IMET	2.65
Barometric Pressure	IMET	2.75	IMET	2.75
Short-wave Radiation	IMET	3.40	VAWR	3.40
Long-wave Radiation	IMET	3.40	VAWR	3.40
Sea Surface Temperature	TPOD # 3835	(0.25)	TPOD # 4228	(0.25)
Bulk Ocean Temperature	VMCM # 0009	(5.00)	VMCM # 0045	(5.00)
Surface Salinity	SEACAT # 143	(1.50)	SEACAT # 1882	(1.50)
Surface Current	VMCM # 0009	(5.00)	VMCM # 0045	(5.00)
Precipitation	IMET	3.10	Stand-Alone	2.75

Baumgartner (1998). Another example is the long-wave data which may too may have radiative heating errors despite our use of the analysis techniques presented by Fairall *et al.*, (1998). Also, Baumgartner *et al.*, (1997) found that during the Arabian Sea buoy deployments, a bird sitting near the radiometers interfered with its operation, but we have not looked for this signal in the PACS data set. The near surface Brancker T-Pod data from 0.25m below the surface is used rather than the floating SST at 0.05m pending further evaluation of the floating SST data. Some of the sensor may still have some biases and calibrations drifts that have not been caught in this initial evaluation. Thus future data releases may have minor calibrations corrections. We suggest using some precautions taken when using this data set and contacting the Upper Ocean Processes Group to obtain updates.

3-2. Subsurface Instrumentation

The raw VMCM data was processed using the WHOI UOP software package (Prada, 1992). The SeaBird SEACAT (SBE-16) raw data was processes initially with SBE SeaSoft software to apply the pre-deployment calibrations, and then converted to EPIC using the UOP software package. The other raw subsurface data were processed and converted into EPIC-compliant Net CDF files, using available pre-deployment calibrations, with IDL and C-code programs developed by UOP. The raw current vectors were rotated by 9.46° and 9.39° for NORTH and SOUTH respectively, to correct for the local magnetic deviation. After initial processing, qualitative checks were performed on the data to identify sensor problems such as spikes, drop-outs or gross errors.

A summary of the data return with brief preliminary processing notes for each subsurface instrument is provided in a separate table for each mooring (Tables 3-2-1, 3-2-2, 3-2-3 and 3-2-4.) No empirical adjustments have been applied at this time to the data to improve agreement among these collocated sensors. The processing notes indicate "full record" if the instrument provided a complete time series and appears to have functioned within specification. If the record ended short, date of the last record is noted in the Table. Also it is noted if one of the measurement parameters form a specific instrument appears to have malfunctioned. For example on PACS1 North, VMCM s/n 013 functioned properly but the rotors stopped working on 14 October 1997. (We believe that there was a fishing vessel near the buoy at that date that entangled its lines on the mooring.) Figures 3-2-5 through 3-2-12 present graphically, as a function of depth and time, the data return for temperature, salinity and velocity.

Composite data sets of upper ocean temperature, velocity and salinity were compiled separately. The composite temperature data set includes data from several different types of

Table 3-2-1. PACS1 North Subsurface Data Return

Depth	Type	Item	S/N		prelim processing notes
0.05	wadar	tpod	275		full record, bad data after Oct 25, 97
0.25	brancker	tpod	3263		full record
0.50	brancker	tpod	4491	*	full record
1.0	brancker	tpod	4485		full record
1.4	brancker	tpod	3258		full record
1.4	seabird	seacat	994	*	full record
2.0	brancker	tpod	3838		full record
2.5	brancker	tpod	3704		full record
3.5	mtr	mtr	3240		full record
5.0	vmcm	vm	016		full record for temp, current, compass, and rotors
7.5	brancker	tpod	3259	*	full record
10.0	vmcm	vm	020	*	full record for temp, current, compass, and rotors
12.5	seabird	seacat	928	*	full record
14.0	vmcm	vm	014	*	full record for temp, current, compass, and rotors
17.5	brancker	tpod	4481	*	full record
20.0	vmcm	vm	015	*	full record for temp and compass, but current and rotor stopped after Oct 14, 97
22.5	seabird	seacat	995		no data, lost at sea
25.0	brancker	tpod	3703	*	full record
29.0	acoustic	raingauge	2		no data
30.0	vmcm	vm	037	*	full record for temp, current, compass, and rotors, except compass all bad
32.5	seabird	seacat	992		no data, connector broken off and flooded
35.0	brancker	tpod	3761	*	full record
37.5					seacat for pacs2 north at this depth
40.0	vmcm	vm	013	*	full record for temp and comp, but current and rotor data stopped after Oct 14, 97
45.0	brancker	tpod	3309	*	full record
47.5					seacat for pacs2 north at this depth
50.0	vmcm	vm	033	*	full record for temp, current, compass, and rotors
60.0	brancker	tpod	4495	*	full record
65.0					seacat for pacs2 north at this depth
70.0	vmcm	vm	031	*	full record for temp, current, compass, and rotors
80.0	microcat	mcat	009	*	full record, with bad points after Sept 10, 97 due to timing problem
90.0	vmcm	vm	026	*	full record for temp, current, compass, and rotors
100.0	brancker	tpod	4487	*	full record
110.0	vmcm	vm	019	*	full record
120.0					instrument for South 1 & 2 mooring at this depth
130.0					instrument for South 1 & 2 mooring at this depth
150.0	brancker	tpod	3662	*	full record
200.0	brancker	tpod	3839	*	full record

Table 3-2-2. PACS2 North Subsurface Data Return

Depth	Type	Item	S/N		prelim processing notes
0.05	wadar	tpod	272		full record
0.25	brancker	tpod	3837		half record, data stopped after May 1, 98
0.50	brancker	tpod	3833	*	full record
1.0	brancker	tpod	3308		no data
1.5	brancker	tpod	3291		no data
1.5	seabird	seacat	2322	*	full record
2.0	brancker	tpod	3296		no data
2.5	brancker	tpod	4402		no data
3.5	mtr	mtr	3241		full record, with bias compare with 0.5m tpod data
5.0	vmcm	vm	017		no data, could not read tape
7.5	seabird	seacat	1881	*	almost full record, data stopped after Aug 8, 1998
10.0	vmcm	vm	044	*	full record for temp, current, compass, and rotors
12.5	brancker	tpod	4488	*	full record
15.0	vmcm	vm	055	*	full record for temp, current, compass, and rotors, except compass all bad
17.5	seabird	seacat	141	*	3/4 of record, data stopped after June 28, 98
20.0	vmcm	vm	010	*	full record for temp, current, compass, and rotors
22.5	brancker	tpod	3508		full record
25.0	brancker	tpod	4493	*	full record
27.5	seabird	seacat	1875		full record
30.0	vmcm	vm	028	*	full record for temp, current, compass, and rotors
32.5					seacat for pacs1 north at this depth
35.0	brancker	tpod	2535	*	full record
37.5	seabird	seacat	1873		full record
40.0	vmcm	vm	027	*	full record for temp, current, compass, and rotors
45.0	brancker	tpod	2541	*	full record
47.5	seabird	seacat	927		full record
50.0	vmcm	vm	002	*	full record for temp, current, compass, and rotors
60.0	brancker	tpod	2537	*	full record
65.0	seabird	seacat	1877		full record
70.0	vmcm	vm	012	*	full record for temp, current, compass, and rotors
80.0	microcat	mcat	011	*	full record
90.0	vmcm	vm	052	*	full record for temp, current, compass, and rotors
100.0	brancker	tpod	3701	*	full record
110.0	vmcm	vm	001	*	almost full record for temp, current, compass, and rotors, data stopped after Aug 15, 98, and the compass looks funny at times
120.0					instrument for South 1 & 2 mooring at this depth
130.0					instrument for South 1 & 2 mooring at this depth
150.0	brancker	tpod	3764	*	full record
200.0	brancker	tpod	3835	*	full record

Table 3-2-3. PACS1 South Subsurface Data Return

Depth	Type	Item	S/N		prelim processing notes
0.05	wadar	tpod	274		full record
0.25	brancker	tpod	3835		full record
0.50	brancker	tpod	3699		full record
1.0	brancker	tpod	3701	*	full record
1.4	brancker	tpod	4492		full record
1.4	seabird	seacat	143	*	full record
2.0	brancker	tpod	4489	*	full record
2.5	brancker	tpod	3764		full record
3.5	mtr	mtr	3243	*	full record
5.0	vmcm	vm	009	*	full record for temp, current, compass, and rotors
7.5	brancker	tpod	3836		full record
10.0	vmcm	vm	011	*	full record for temp, current, compass, and rotors
12.5	seabird	seacat	993	*	full record
14.0	vmcm	vm	056	*	full record for temp, current, compass, and rotors
17.5	brancker	tpod	3265	*	full record
20.0	vmcm	vm	038	*	full record for temp, current, compass, and rotors, except compass all bad
22.5	seabird	seacat	991	*	full record
25.0	brancker	tpod	4494	*	full record
27.5	ACH	ACH	0126		first half record with lots bad data points, data stopped after Aug 20, 97
30.0	vmcm	vm	039	*	full t record for temp, current, compass, and rotors, except compass all bad
32.5	seabird	seacat	929		full record
35.0	brancker	tpod	3279		no data, did not record
37.5					seacat for pacs2 south at this depth
40.0	vmcm	vm	025	*	full record for temp, current, compass, and rotors
45.0	brancker	tpod	4483	*	full record
47.5					seacat for pacs2 south at this depth
50.0	vmcm	vm	032	*	full record for temp, current, compass, and rotors
60.0	brancker	tpod	3667		full record
65.0					seacat for pacs2 south at this depth
70.0	vmcm	vm	018	*	full record for temp, current, compass, and rotors
80.0	microcat	mcat	010	*	full record
90.0	vmcm	vm	008	*	full record for temp, current, compass, and rotors
100.0	brancker	tpod	3283	*	full record
110.0	vmcm	vm	021	*	full record for temp, current, compass, and rotors
120.0	sherman	CM	001		no data, internal connector failed
130.0	FSI	cm	1428A		full record
150.0	brancker	tpod	4482		no data, did not record
200.0	brancker	tpod	3762	*	full record

Table 3-2-4. PACS2 South Subsurface Data Return

Depth	Type	Item	S/N		prelim processing notes
0.05	wadar	tpod	273		full record, with few sparks compare to the data at 1 meter depth
0.25	brancker	tpod	4228		full record, with bias
0.50	brancker	tpod	3274		no data
1.0	brancker	tpod	3271	*	full record
1.4	brancker	tpod	4486		full record
1.5	seabird	seacat	1882	*	almost full record, data stopped after Sept. 5, 98 due to battery problem
2.0	brancker	tpod	3830	*	full record
2.5	brancker	tpod	3834		no data return
3.5	mtr	mtr	3242	*	full record
5.0	vmcm	vm	045	*	full record for temp, current, compass, and rotors
7.5	seabird	seacat	1874		3/4 record, data stopped after July 2, 98
10.0	vmcm	vm	023	*	full record for temp, current, compass, and rotors
12.5	brancker	tpod	3763	*	full record
15.0	vmcm	vm	041	*	full record for temp, current, compass, and rotors
17.5	seabird	seacat	1878	*	full record
20.0	vmcm	vm	043	*	full record for temp, current, compass, and rotors
22.5	brancker	tpod	3506	*	full record
25.0	brancker	tpod	3507	*	full record
27.5	Bio-Optical				no data
30.0	vmcm	vm	022	*	full record for temp, current, compass, and rotors
32.5					seacat for pacs1 south at this depth
35.0	brancker	tpod	3301		full record
37.5	seabird	seacat	1876		full record
40.0	vmcm	vm	051	*	full record for temp, current, compass, and rotors
45.0	brancker	tpod	3831	*	full record
47.5	seabird	seacat	142		full record
50.0	vmcm	vm	053	*	full record for temp, current, compass, and rotors
60.0	brancker	tpod	3702		no data
65.0	seabird	seacat	1880		full record
70.0	vmcm	vm	034	*	full record for temp, current, compass, and rotors
80.0	microcat	mcat	008	*	full record
90.0	vmcm	vm	030	*	full record for temp, current, compass, and rotors
100.0	brancker	tpod	3299	*	full record
110.0	vmcm	vm	040	*	full record for temp, current, compass, and rotors
120.0	Sherman	CM	001		no data
130.0	new vmcm	vm	201		no data
150.0	brancker	tpod	2533		full record
200.0	brancker	tpod	2536	*	full record

Figure 3-2-5. PACS1 North Temperature Data Return Bar Charts

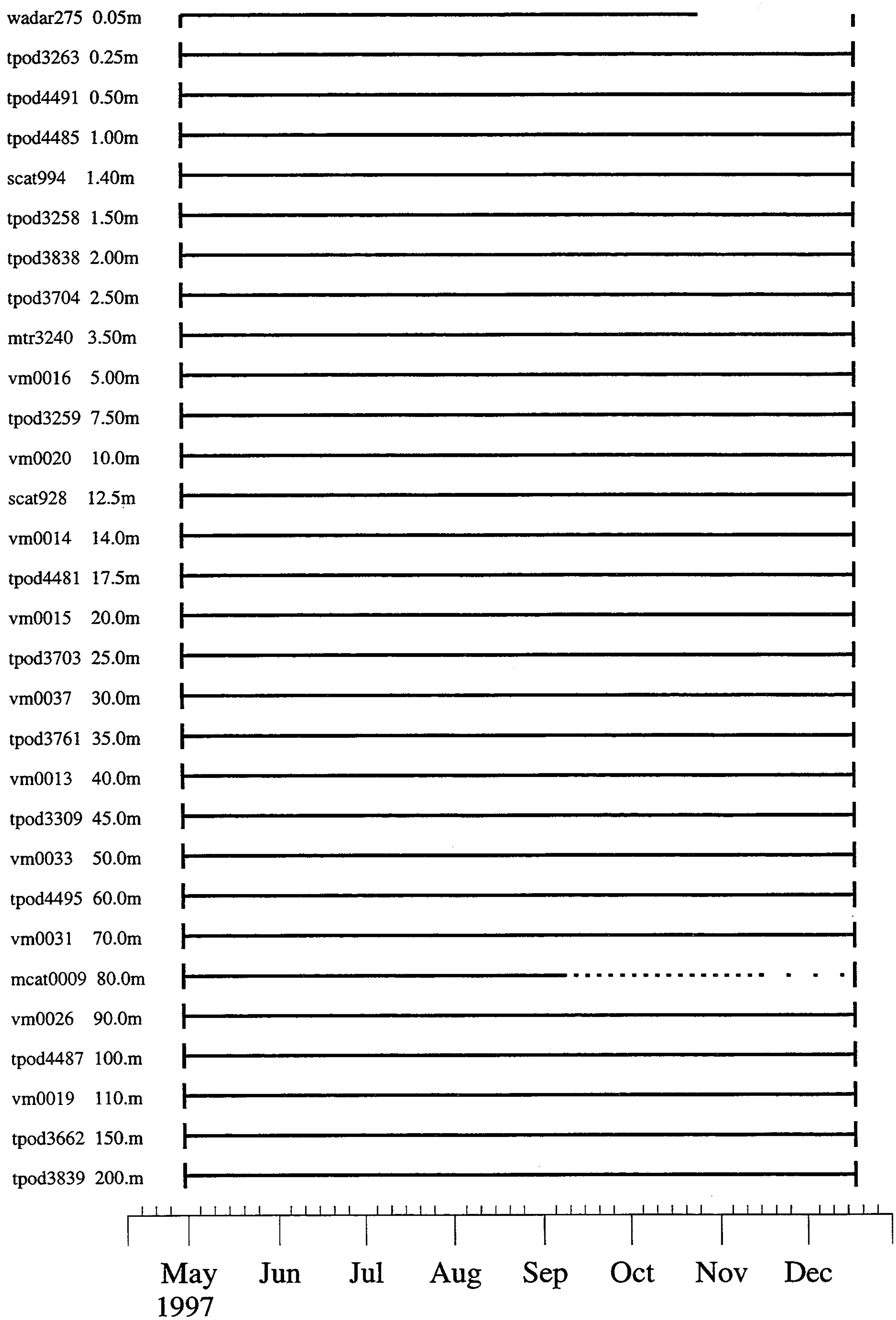


Figure 3-2-6. PACS2 North Temperature Data Return Bar Charts

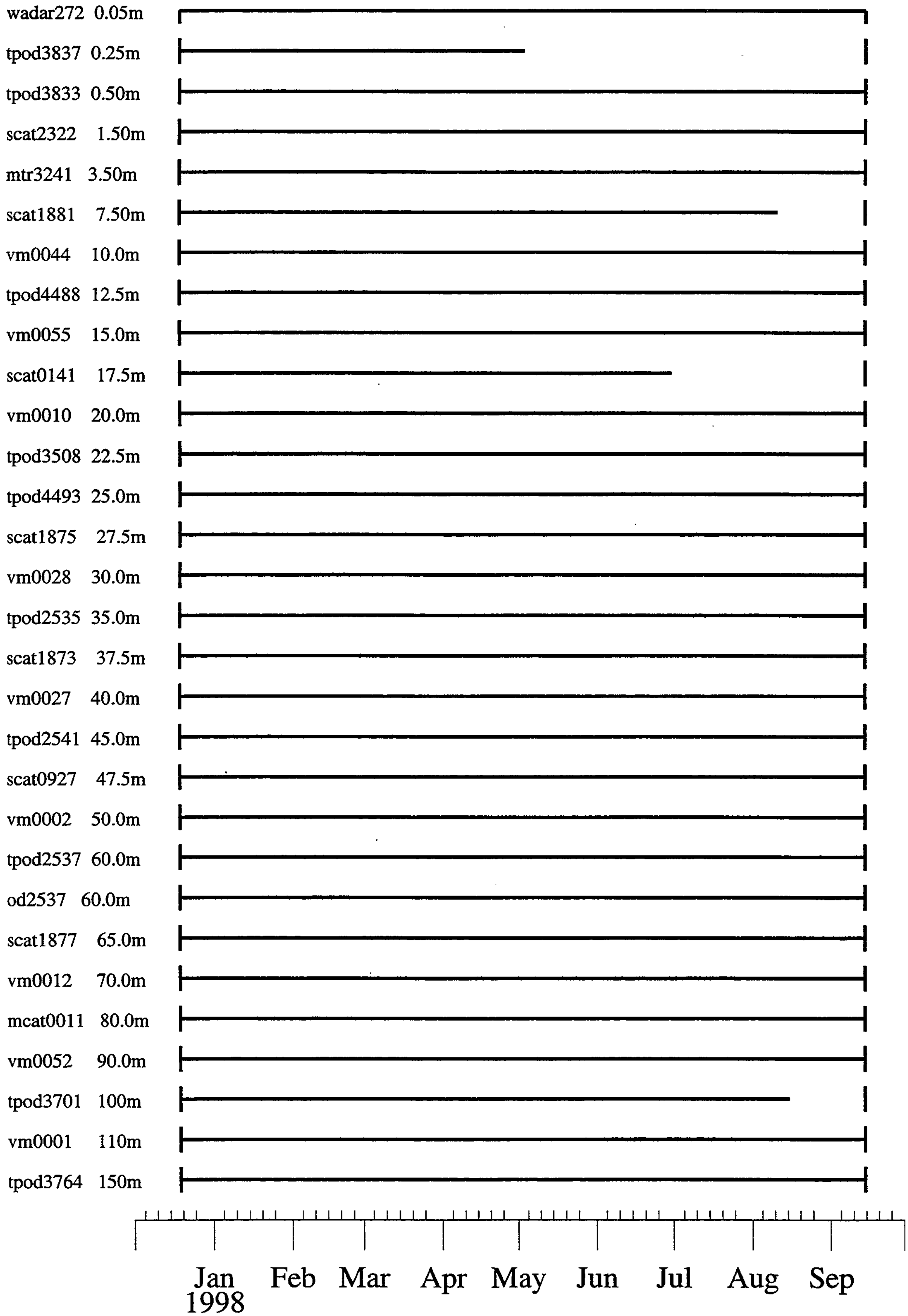


Figure 3-2-7. PACS1 South Temperature Data Return Bar Charts

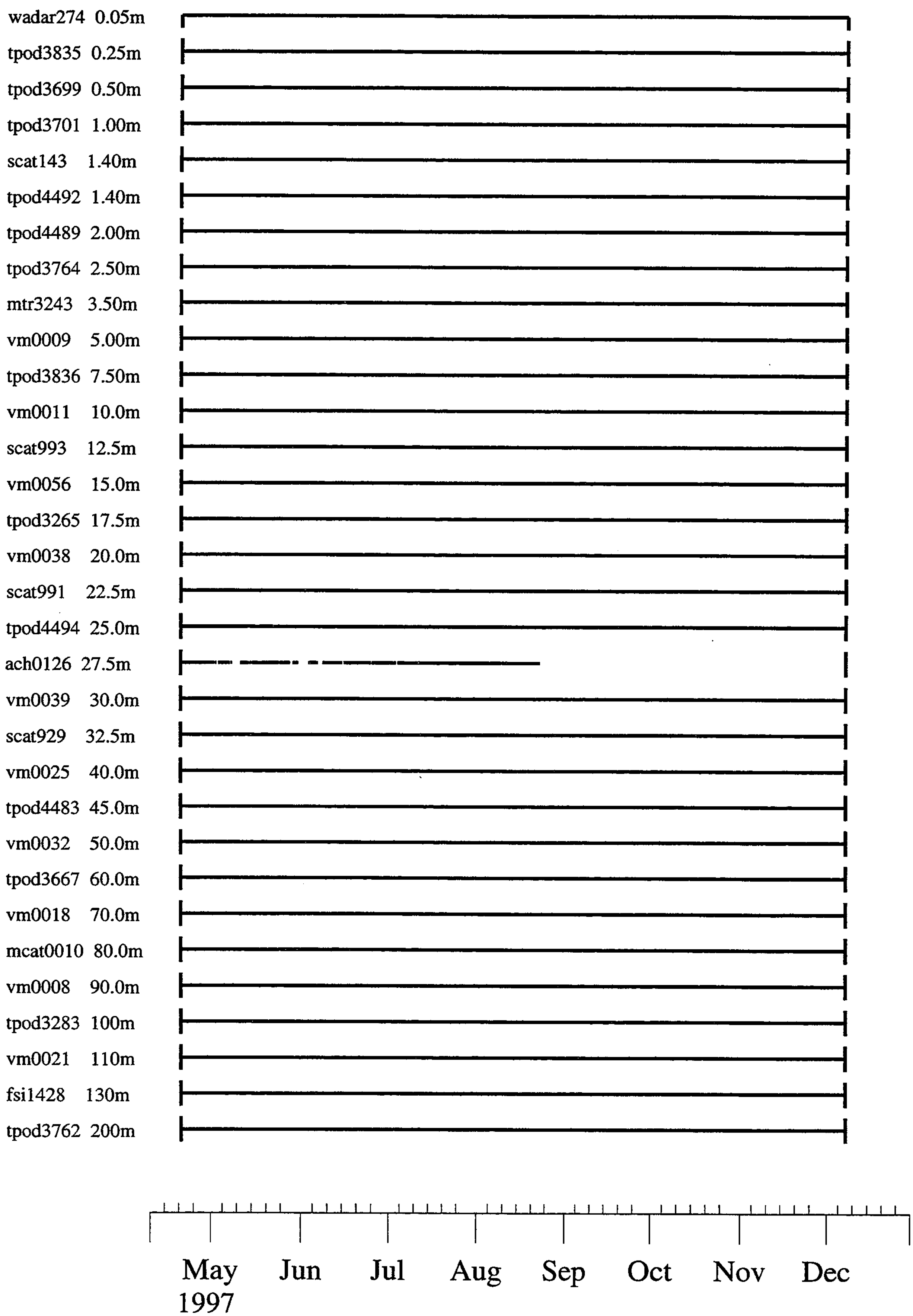


Figure 3-2-8. PACS2 South Temperature Data Return Bar Charts

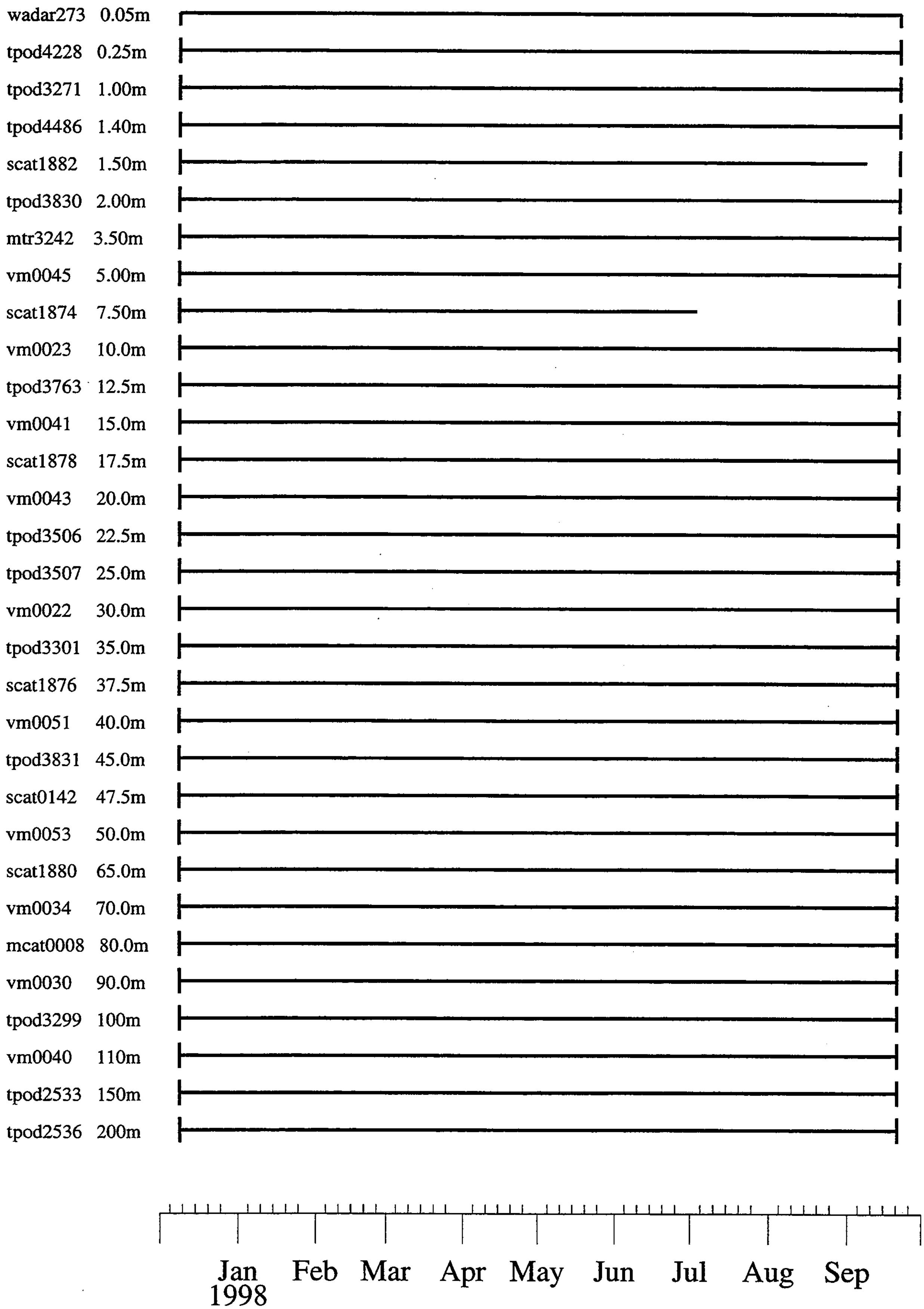


Figure 3-2-9. PACS1 North Velocity and Salinity Data Return Bar Charts

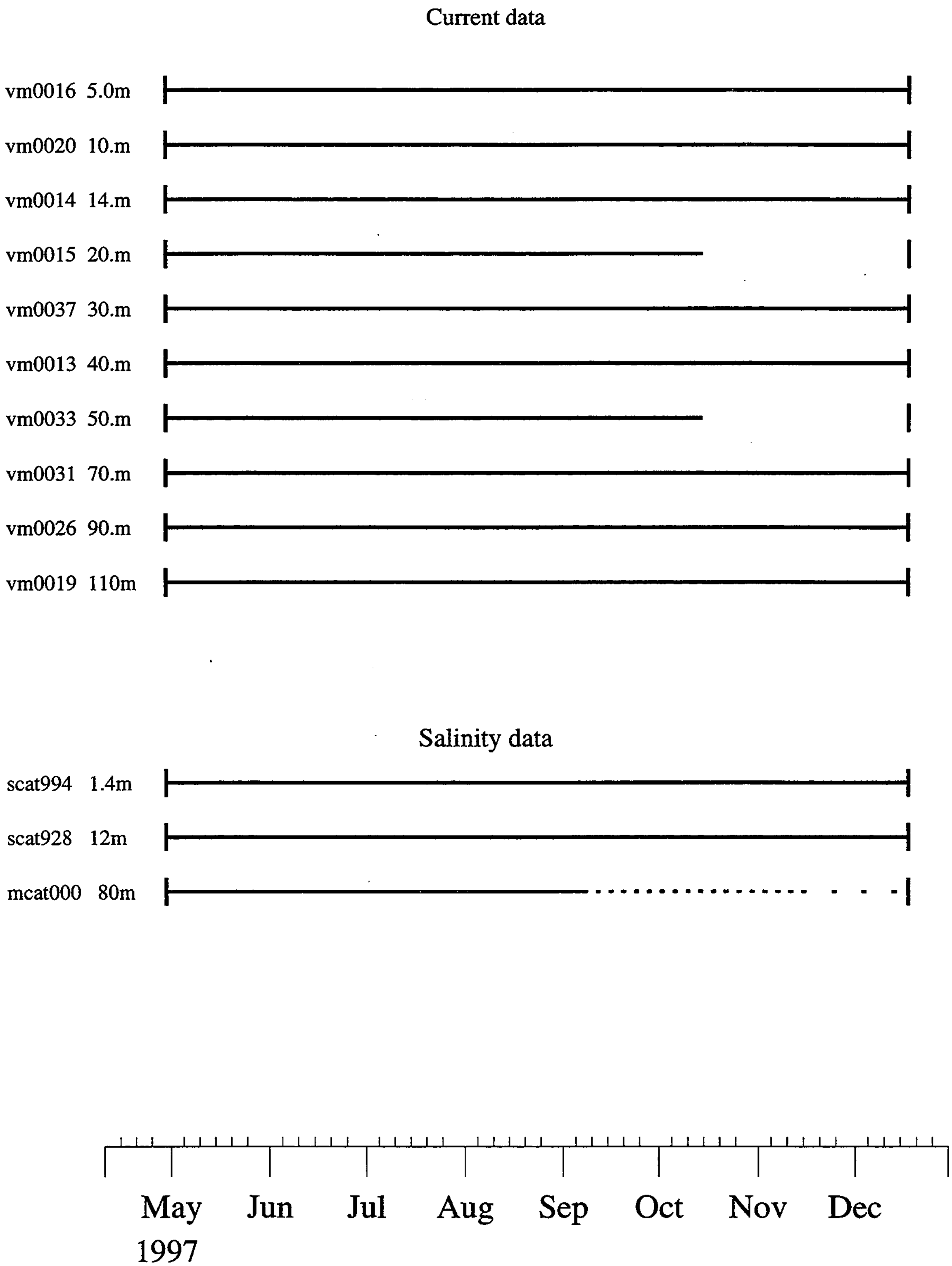


Figure 3-2-10. PACS2 North Velocity and Salinity Data Return Bar Charts

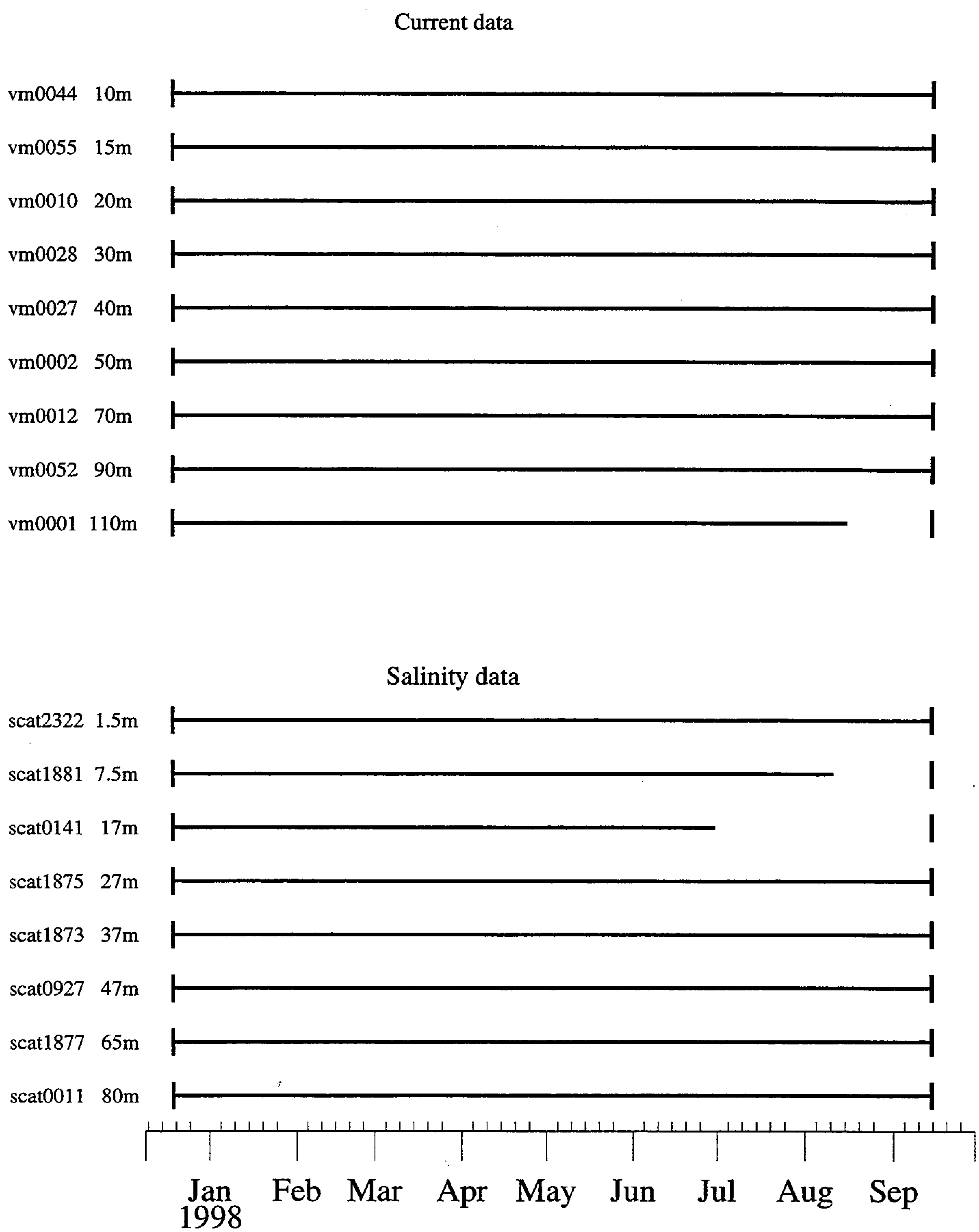


Figure 3-2-11. PACS1 South Velocity and Salinity Data Return Bar Charts

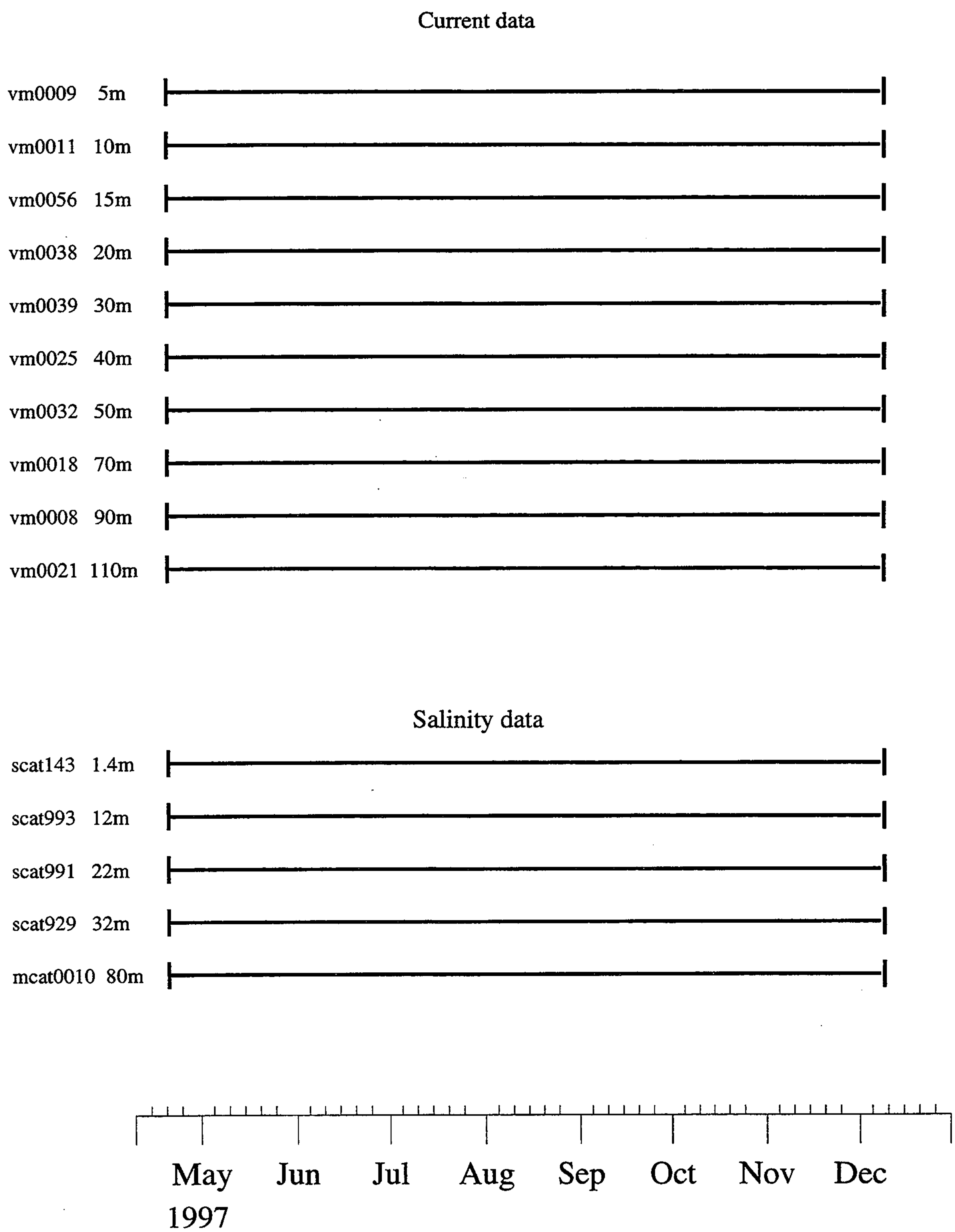
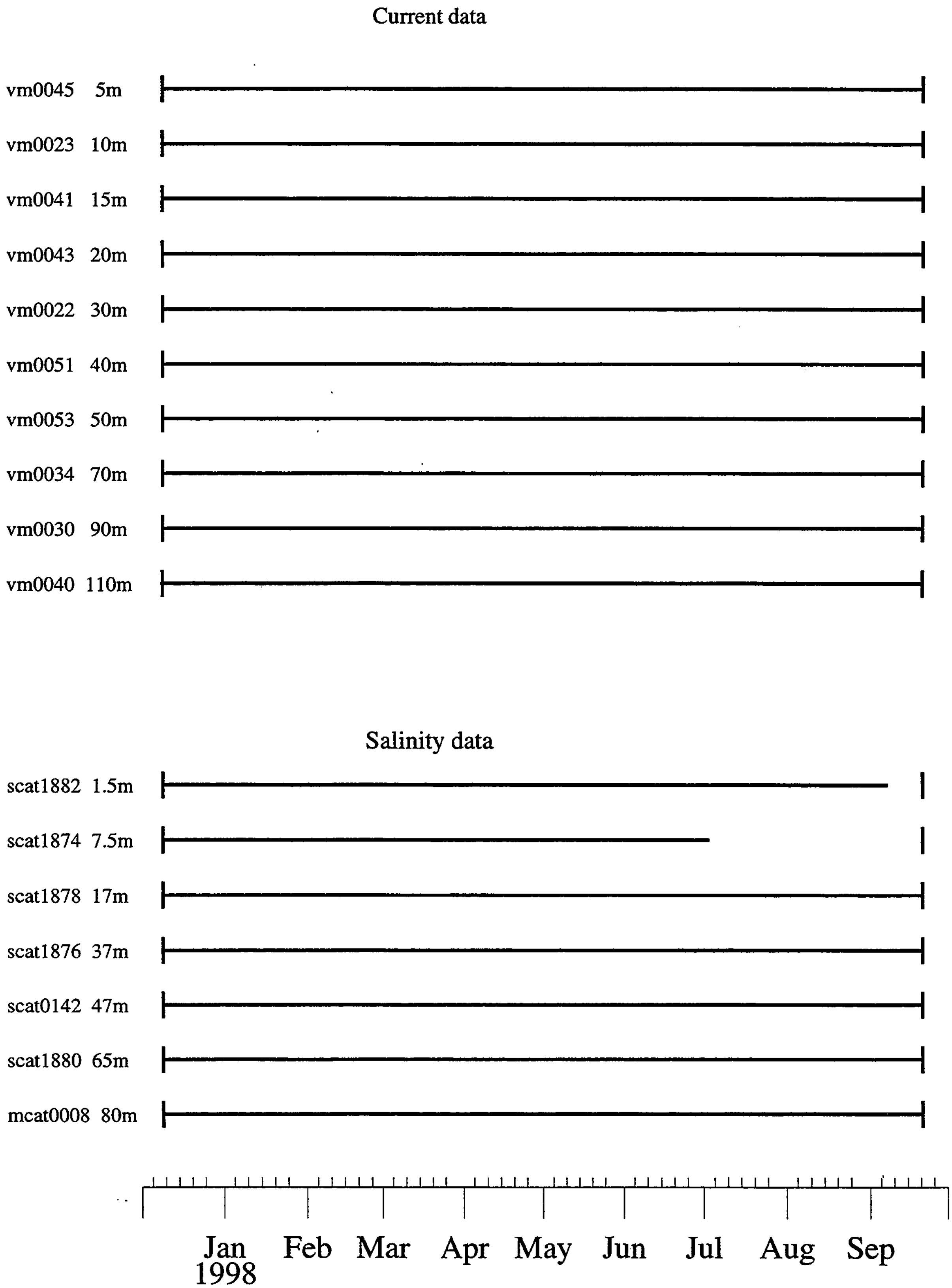


Figure 3-2-12. PACS2 South Velocity and Salinity Data Return Bar Charts



instruments. Note all functioning temperature records were included in the composite. A star (*) next to an instrument listed in Tables 3-2-1 through 3-2-4 indicates the record was included in the composite data set. All functioning VMCM's were included in the composite velocity data set and all SBE instruments were included in the salinity data set. No bias corrections have been applied to any of the preliminary data. All statistics and plots shown in Sections 4 and 5 are derived from these composite data sets.

3-3. Freshwater, Heat and Momentum Fluxes

Air-sea heat and momentum fluxes were estimated from the meteorological and near-surface oceanographic measurements using a bulk flux algorithm developed for TOGA COARE (Fairall *et al.*, 1996a). This algorithm is based on methods developed by Liu *et al.* (1979) with modifications for, but not limited to, low wind regimes. The algorithm also includes cool skin and warm layer adjustments based on Fairall *et al.* (1996b) to account for the cooling of the upper few millimeters of the ocean due to sensible, latent and outgoing long-wave radiation heat loss and warming of the upper few meters of the ocean due to absorption of short-wave radiation. The cool skin was employed in the calculations presented here but not the warm layer component of the algorithm. The wind speed relative to the sea surface used in the algorithm was calculated using the observed wind speed vectors and subtracting the near surface current record from the mooring.

Since only incoming short- and long-wave radiation were measured, the outgoing components of radiation were estimated using the TOGA COARE Bulk Flux Algorithm. This algorithm assumes a constant surface short-wave albedo. Outgoing long-wave radiation was estimated as $\varepsilon\sigma T^4$ where ε is the emissivity of the sea surface ($\varepsilon = 0.97$), σ is the Stefan-Boltzmann constant and T is the sea surface skin temperature in °K. The skin temperature from the cool skin adjustment was used as the sea surface temperature, since the outgoing long-wave radiation is dependent on the interfacial temperature which may be quite different from the shallowest temperature measurement.

Only minimal processing has been done to the precipitation data from the R. M. Young rain gauges. They should be used with caution. The raw time series of the level of water in the gauge reservoir was first-differenced in time, the few large negative spikes associated with the self-siphoning were removed and replaced with zeroes, and then the data was re-integrated to provide a time series of accumulated rainfall. No other filtering or corrections were applied. The evaporation rate is derived directly from the latent heat flux parameter calculated from the bulk formulae.

Section 4: PACS North Statistics and Plots

Statistics of the meteorological measurements and estimated heat, momentum and freshwater fluxes for the 17 month long experiment are presented in Table 4-1 for PACS North. Each table contains the mean, standard deviation, minimum and maximum of the meteorological measurements and fluxes. Meteorological observations are presented next followed by precipitation, heat and flux time series, contours of subsurface temperatures with mixed layer depth (the mixed layer depth in these plots was computed as the depth at which the temperature differs from the sea surface temperature (measured at 0.17 m) by 0.1°C), velocity stick plots with current speed overlaid, progressive vector diagrams and auto spectra for meteorological, flux, temperature and velocity variables. Band averaging was used in each of the autospectra plots and the 95% confidence limits are shown. The first 5 frequencies were averaged over 3 bands and the number of bands averaged was doubled every 10 frequencies thereafter (i.e., frequencies 6-15 were averaged over 6 bands, frequencies 16-25 were averaged over 12 bands, frequencies 26-35 were averaged over 24 bands, etc.). See the following table for the page numbers of the different plots.

Table 4-1. Statistics for Combined Meteorological and Air-Sea Flux Time Series for PACS North. The time period is 29/04/1997 23:00 UTC to 14/09/1998 14:00 UTC. (48256 data points)

Variable	Unit	Mean	Std Dev.	Minimum	Maximum
Air Temperature	°C	26.783	1.020	22.390	29.701
Relative Humidity	%	84.722	6.485	57.910	101.207
East Component	m s^{-1}	-2.548	4.383	-12.281	11.847
North Component	m s^{-1}	-2.167	3.494	-10.673	14.365
Scalar Averaged Wind Speed	m s^{-1}	6.101	2.481	0.000	26.7000
Short-wave Radiation	W m^{-2}	225.310	315.407	-0.004	1246.177
Long-wave Radiation	W m^{-2}	419.400	19.926	352.432	531.922
Barometric Pressure	mbar	1011.184	2.188	1003.185	1019.490
Sea Temperature at 0.25m	°C	27.783	0.953	25.576	30.921
Sea Temperature at 5.0m	°C	27.745	0.925	25.595	29.473
Specific Humidity	g/kg	18.373	1.707	12.427	22.322
Precipitation Rate	mm hr^{-1}	0.196	1.870	-10.622	81.081
Evaporation Rate	mm hr^{-1}	-0.156	0.077	-0.549	-0.006
Wind Stress Magnitude	N m^{-2}	0.080	0.061	0.000	0.658
Sensible Heat Flux	W m^{-2}	-8.103	7.999	-90.082	10.326
Latent Heat Flux	W m^{-2}	-105.340	52.374	-371.060	-4.039
Net Short-wave Radiation	W m^{-2}	212.918	298.059	-0.004	1177.637
Net Long-wave Radiation	W m^{-2}	-43.322	19.044	-104.408	55.498
Net Heat Flux	W m^{-2}	56.144	300.279	-430.552	1034.821
Skin Temperature	°C	27.621	0.962	25.359	32.956
Wind Speed At 10m [a]	m s^{-1}	6.683	2.851	0.112	17.964
Air Temperature 2m [a]	°C	26.755	1.027	22.312	29.676
Relative Humidity2m [a]	%	84.729	6.579	57.569	101.660

([a]) estimated from boundary layer profile

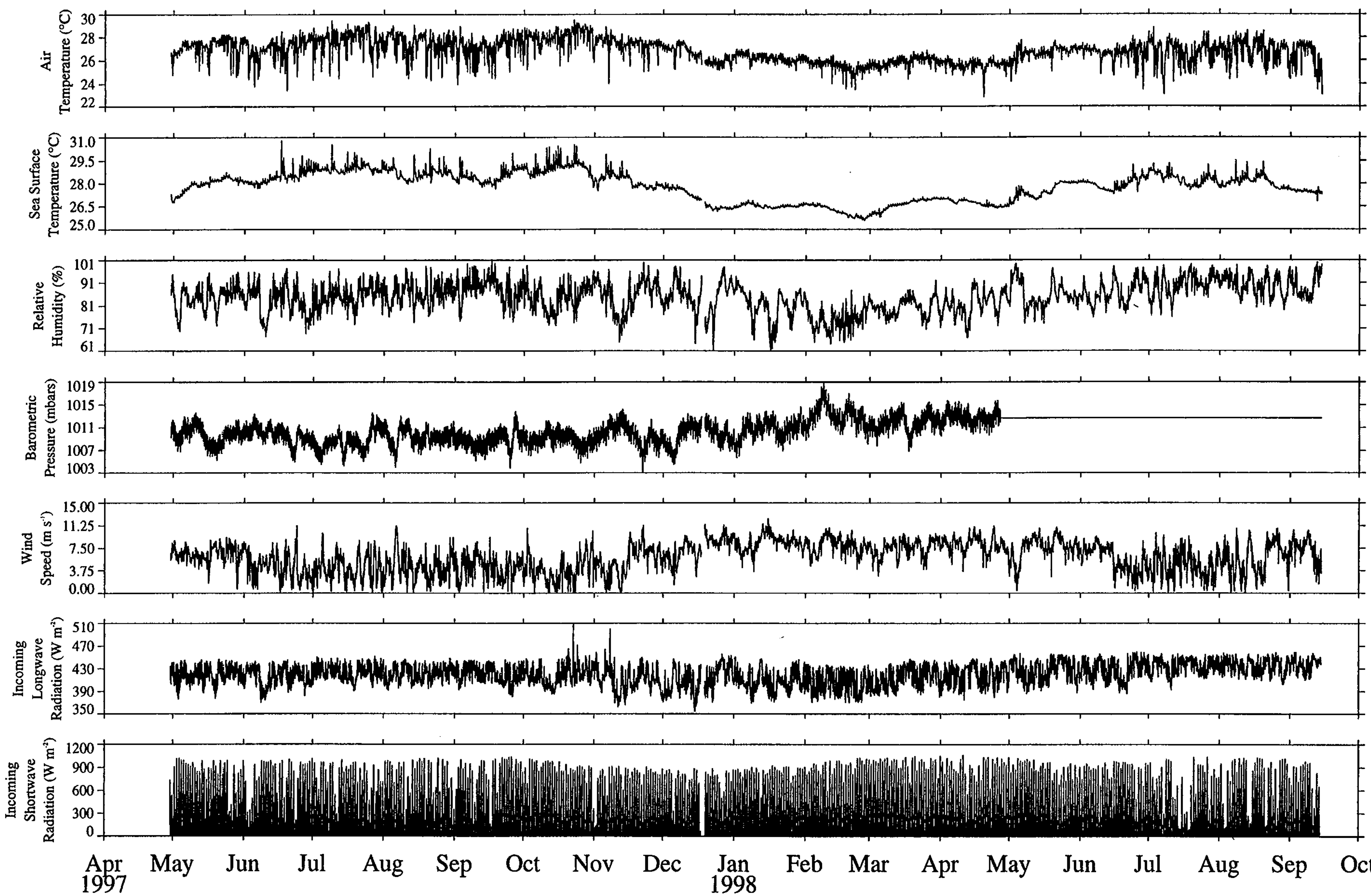


Figure 4-1. Hourly time series of meteorological observations. Incoming short-wave radiation has a 48 hour running mean superimposed on the hourly time series. (PACS North)

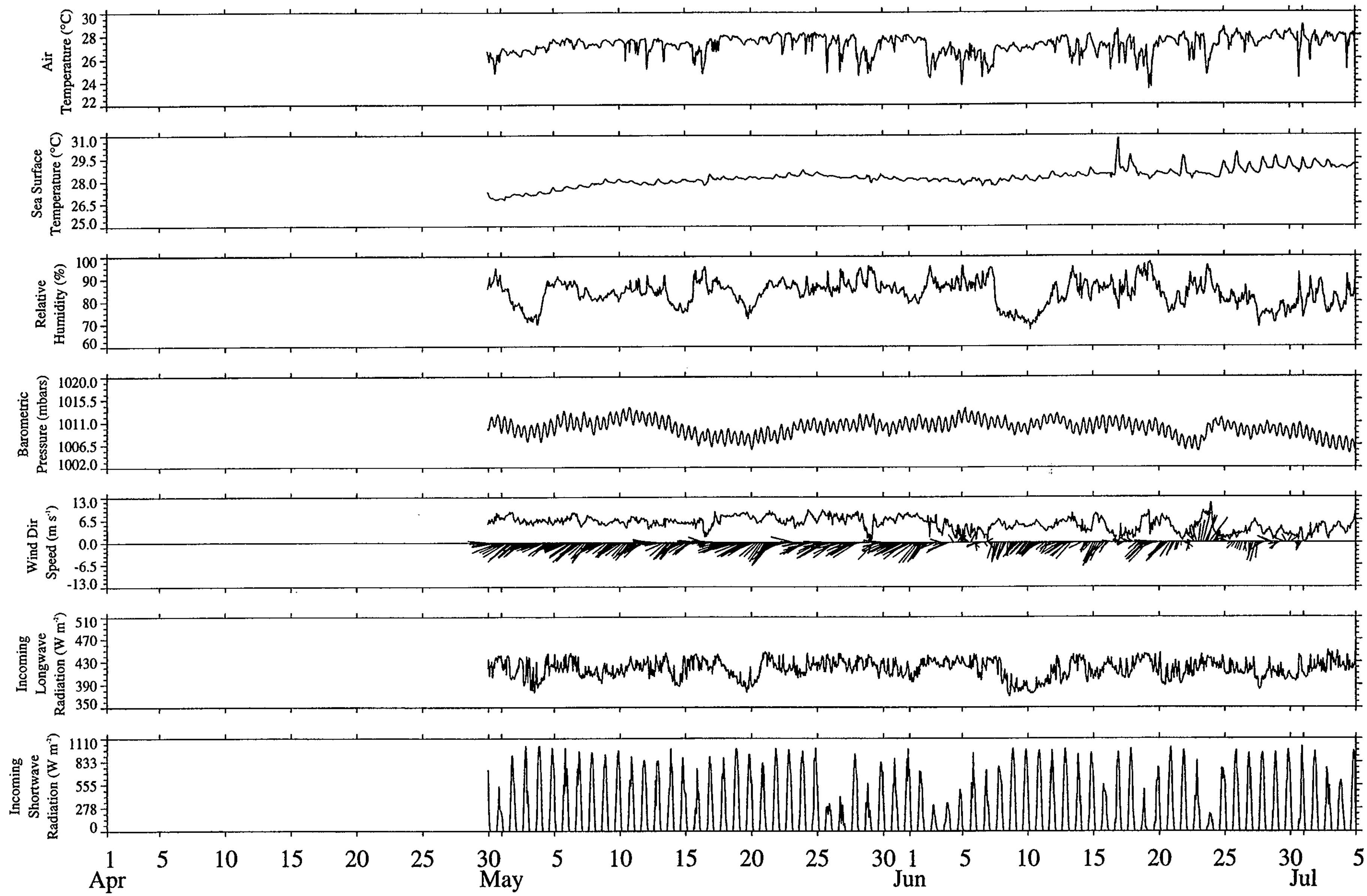


Figure 4-2. Hourly time series of meteorological observations for April through June 1997.
(PACS North)

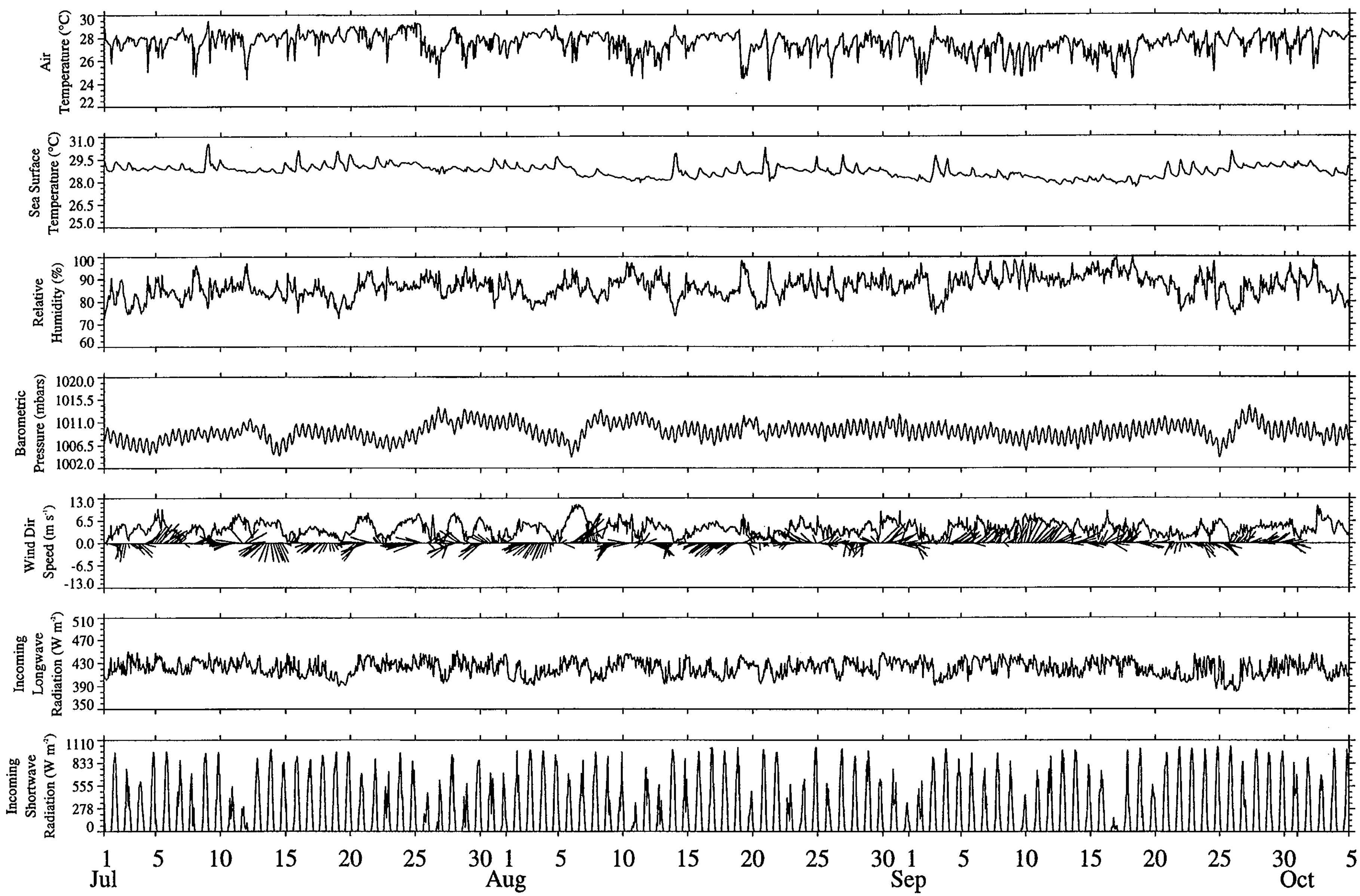


Figure 4-3. Hourly time series of meteorological observations for July through September 1997.
(PACS North)

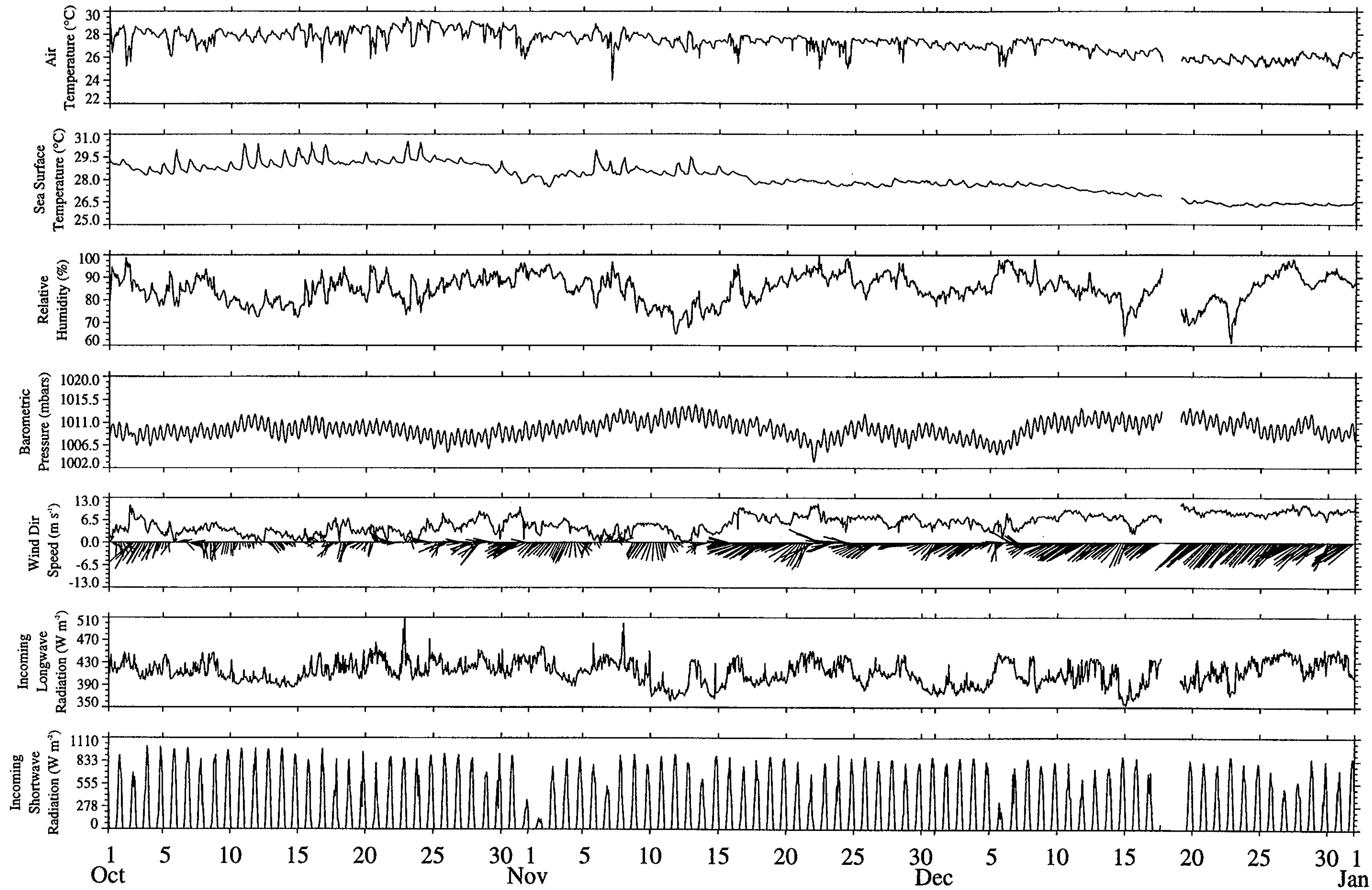


Figure 4-4. Hourly time series of meteorological observations for October through December 1997.
(PACS North)

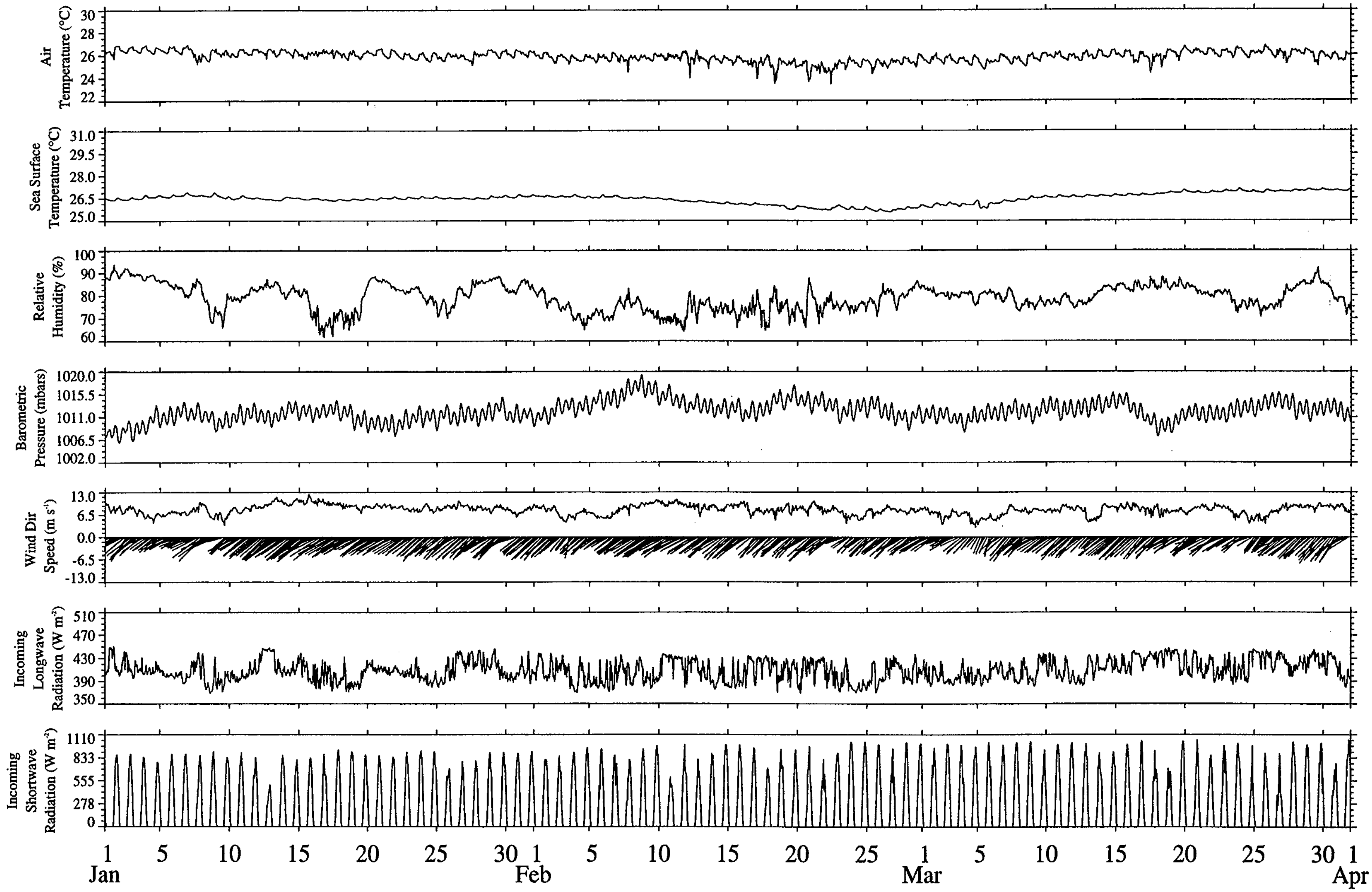


Figure 4-5. Hourly time series of meteorological observations for January through March 1998.
(PACS North)

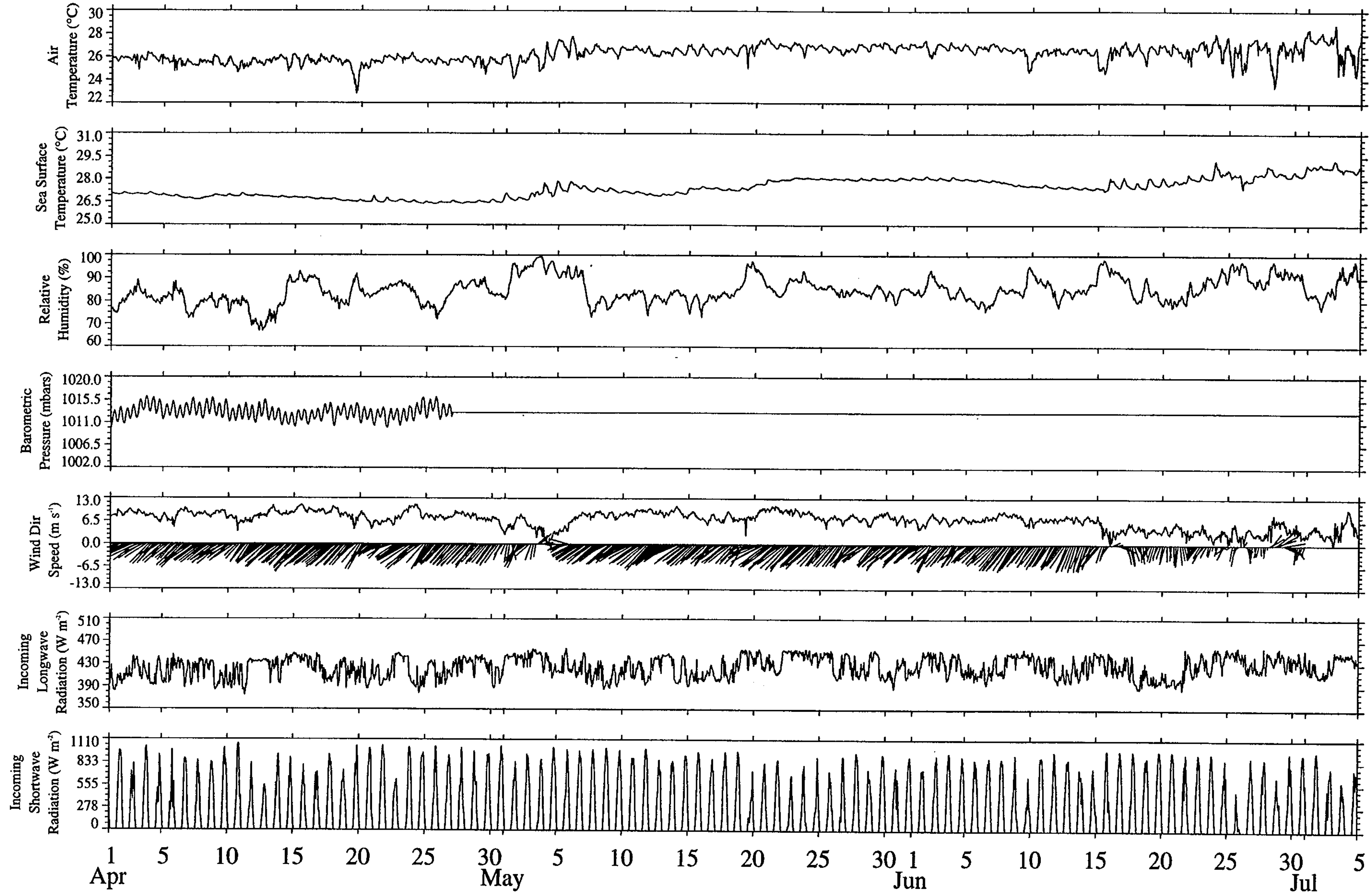


Figure 4-6. Hourly time series of meteorological observations for April through June 1998. (PACS North)

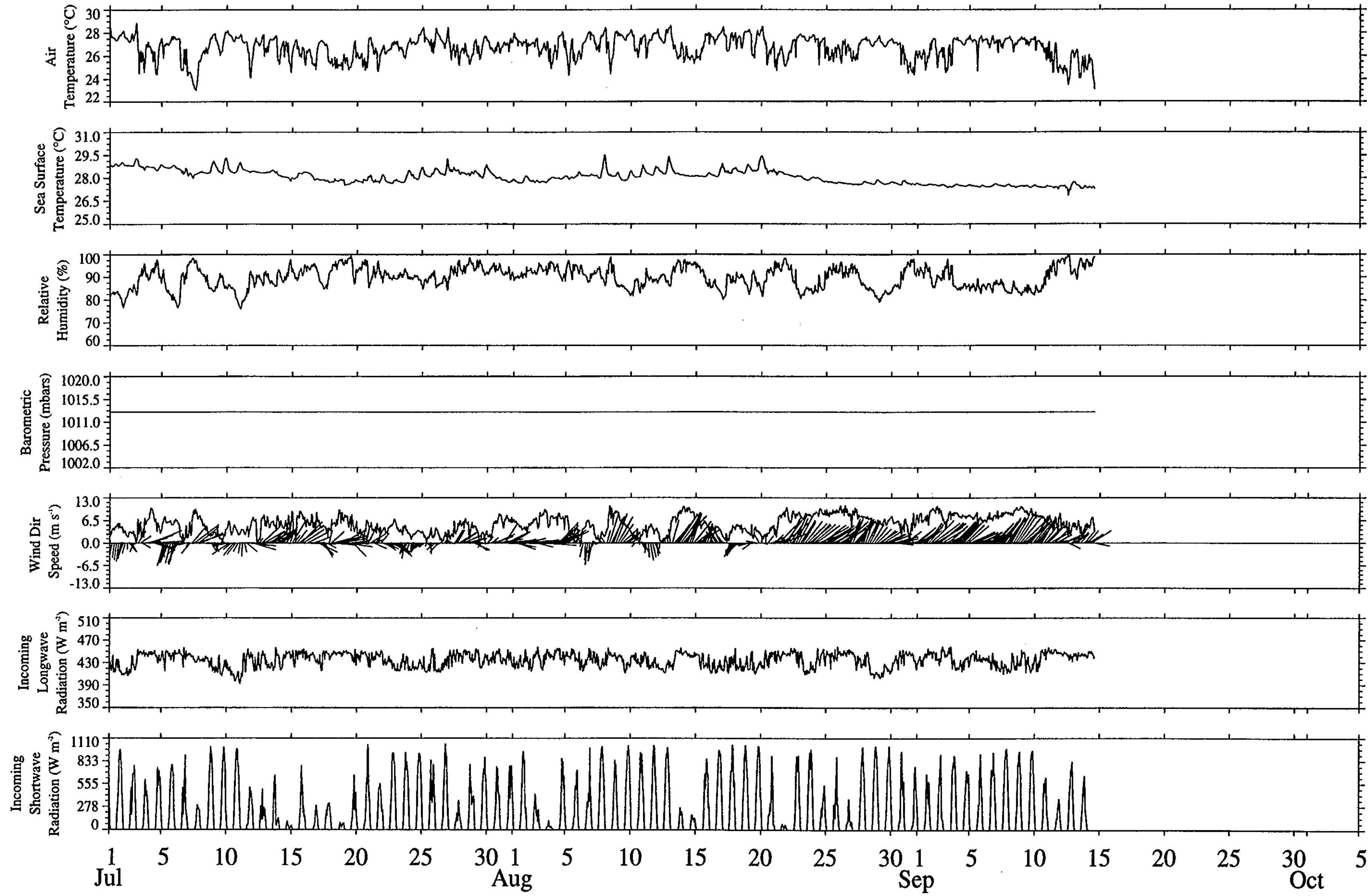


Figure 4-7. Hourly time series of meteorological observations for July through September 1998. (PACS North)

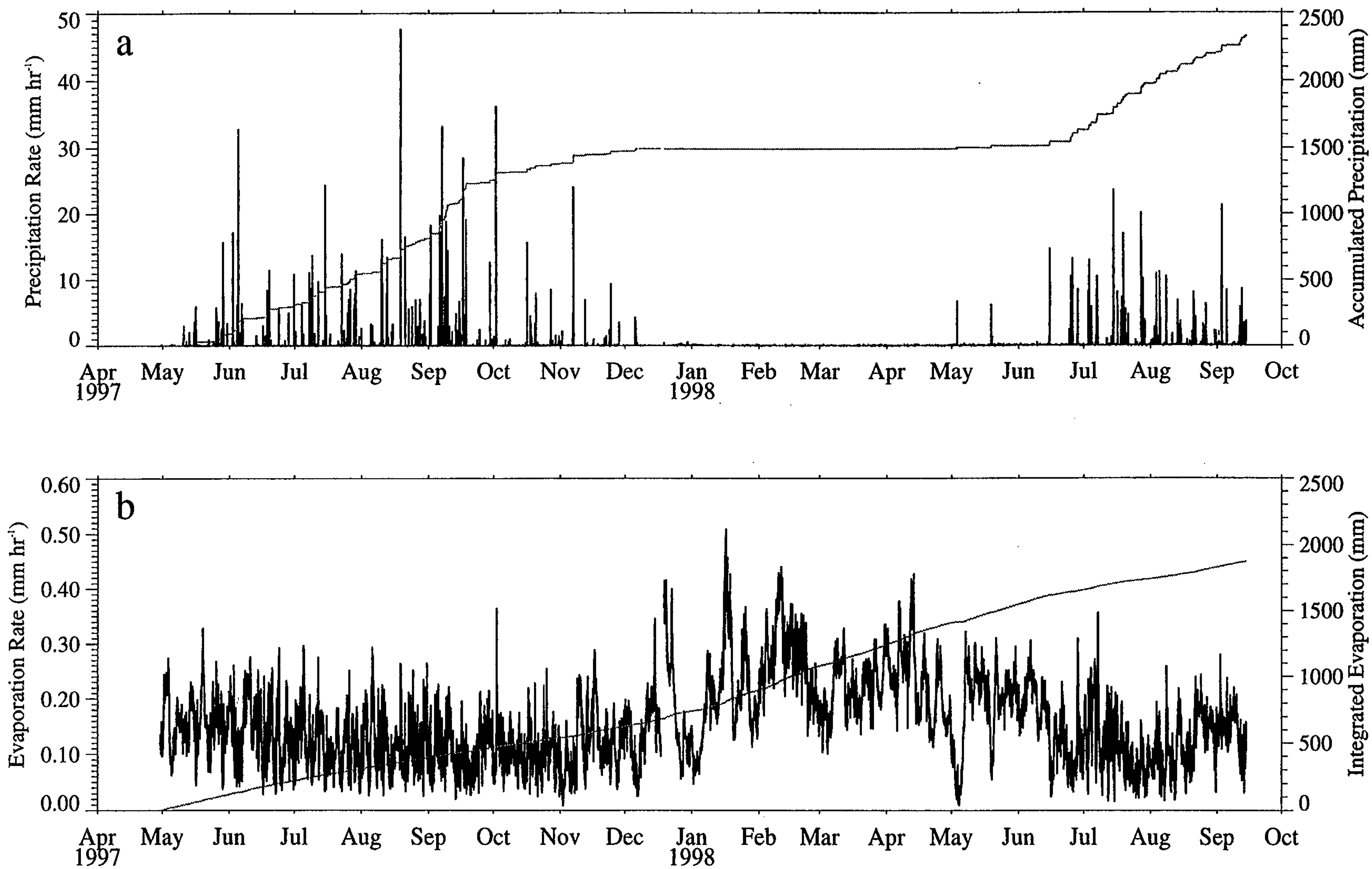


Figure 4-8. (a) Hourly averaged precipitation rate (black) and accumulated precipitation (gray) from IMET self-siphoning rain gauge. (b) Hourly averaged evaporation rate (black) and integrated evaporation (gray) from bulk formulae. (PACS North)

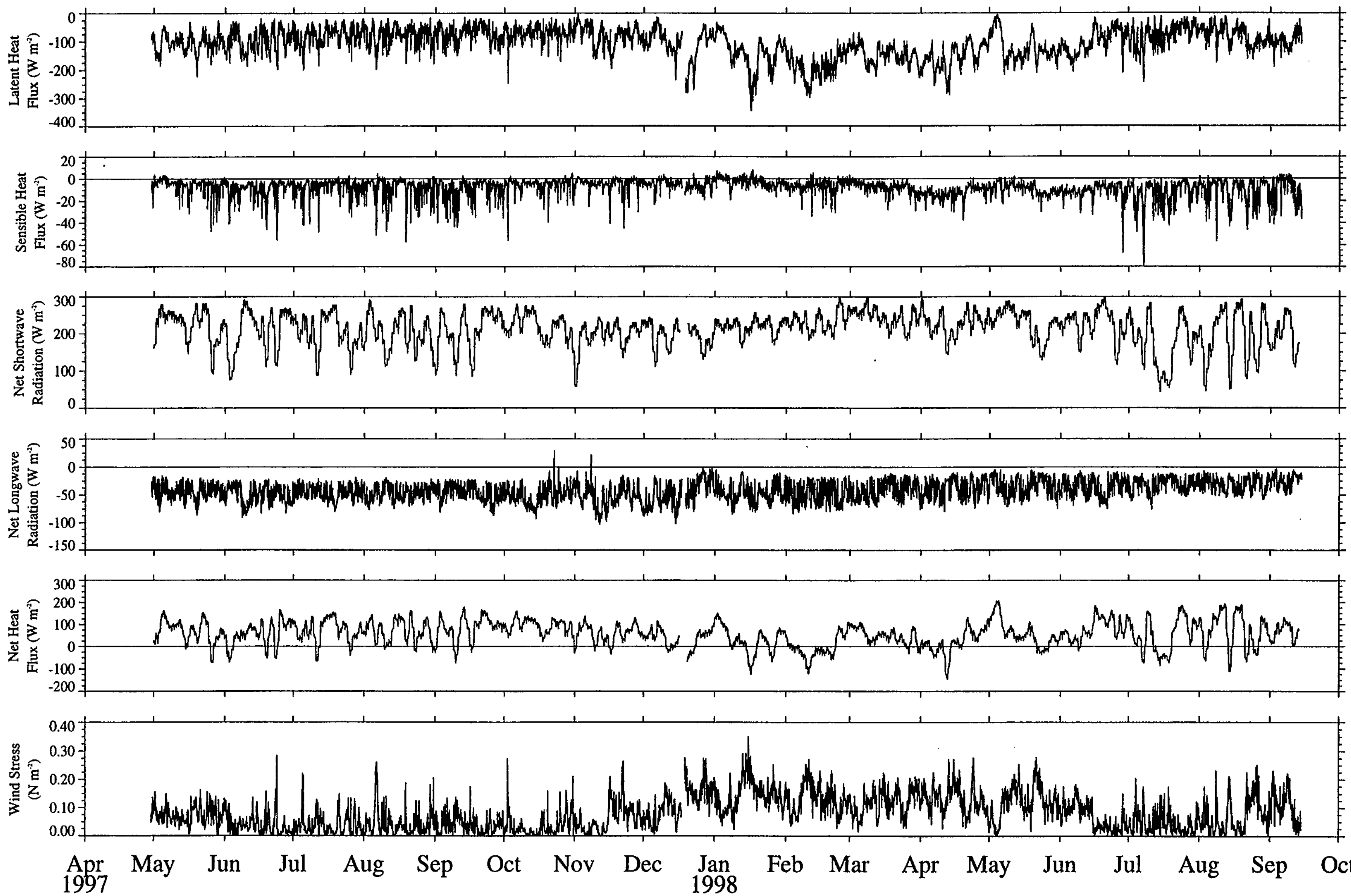


Figure 4-9. Hourly time series of estimated heat and momentum fluxes. Net short-wave and net heat flux each have a 48 hour running mean applied. (PACS North)

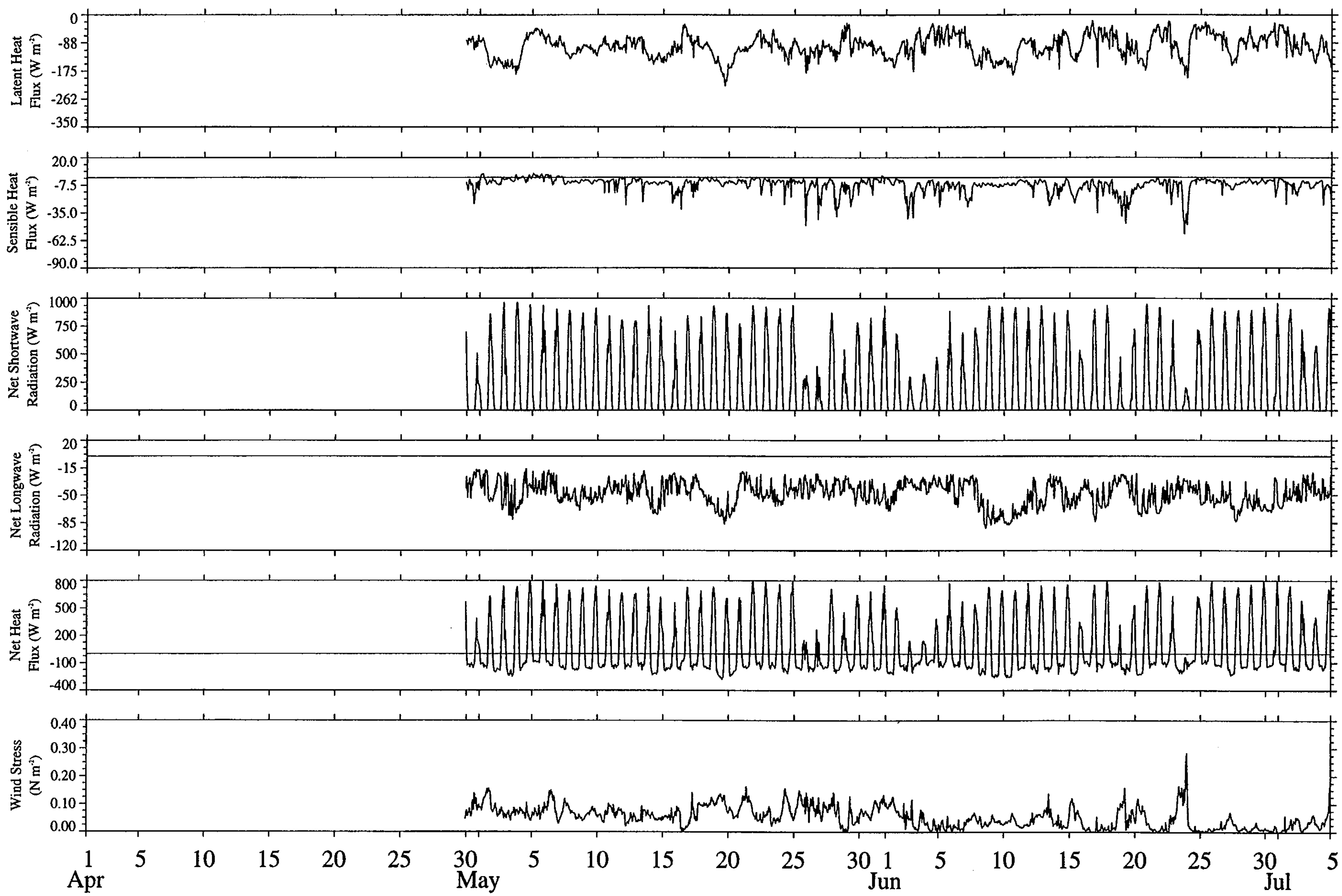


Figure 4-10. Hourly time series of estimated heat and momentum fluxes for April through June 1997.
(PACS North)

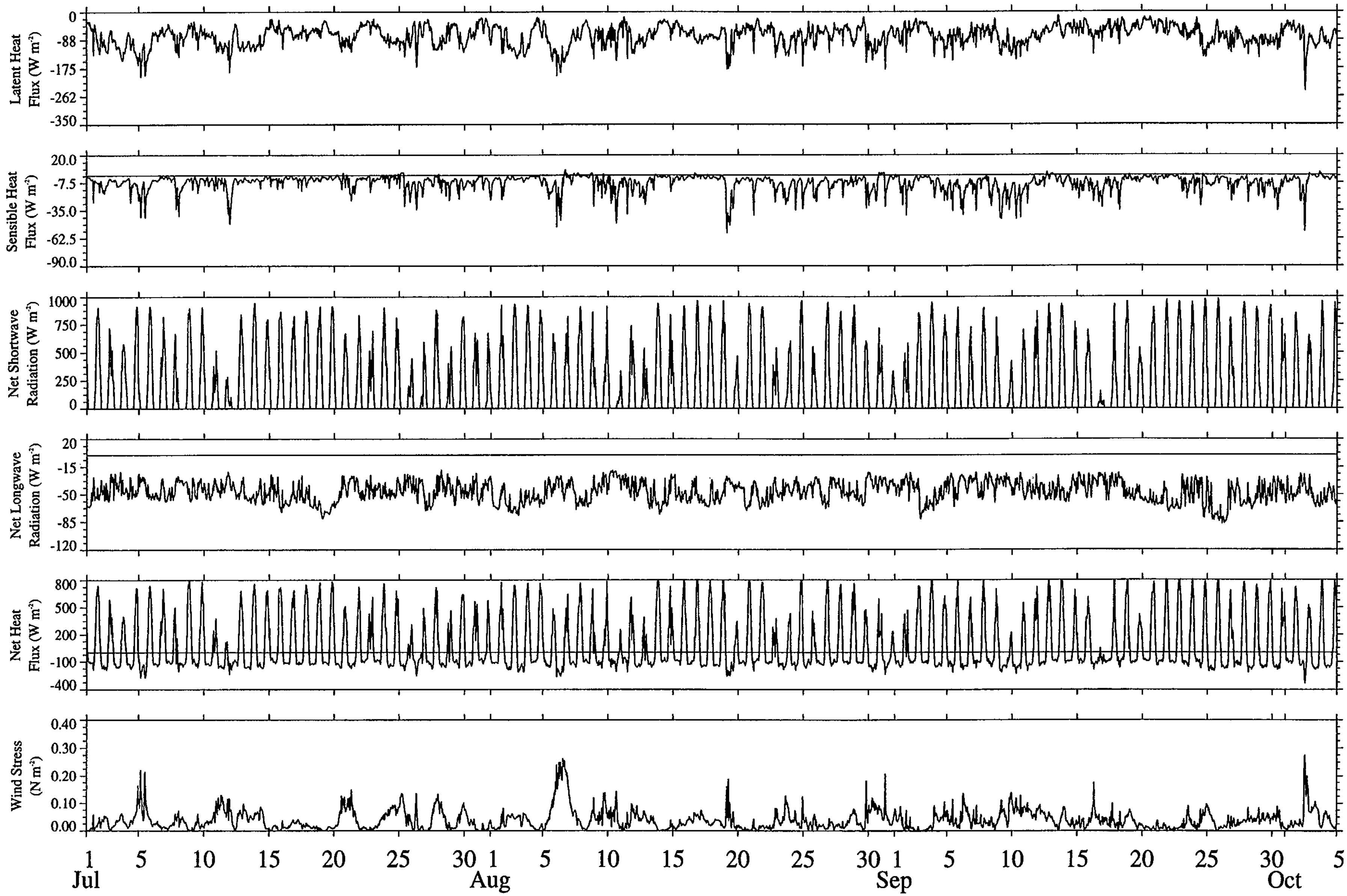


Figure 4-11. Hourly time series of estimated heat and momentum fluxes for July through September 1997. (PACS North)

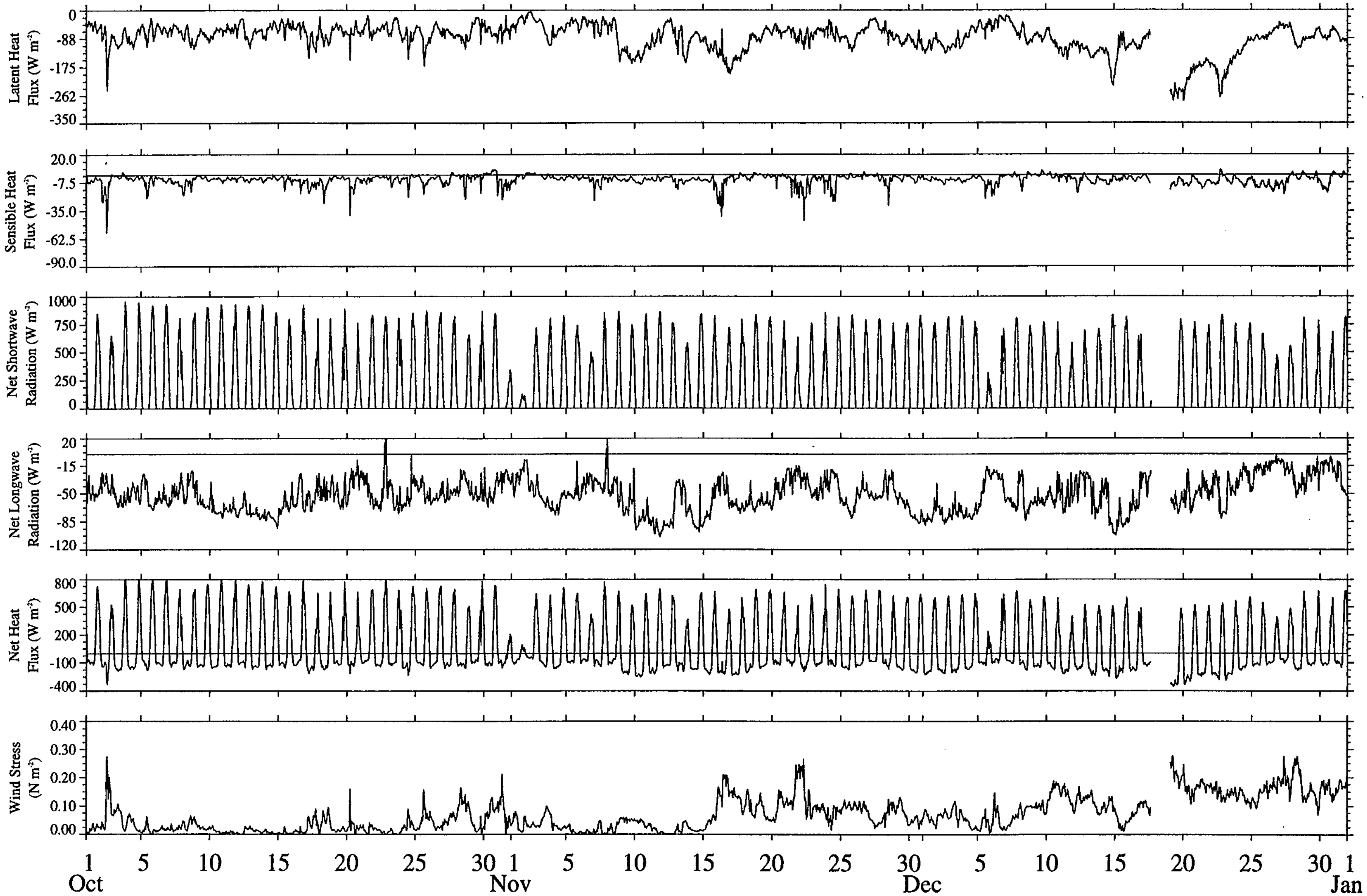


Figure 4-12. Hourly time series of estimated heat and momentum fluxes for October through December 1997. (PACS North)

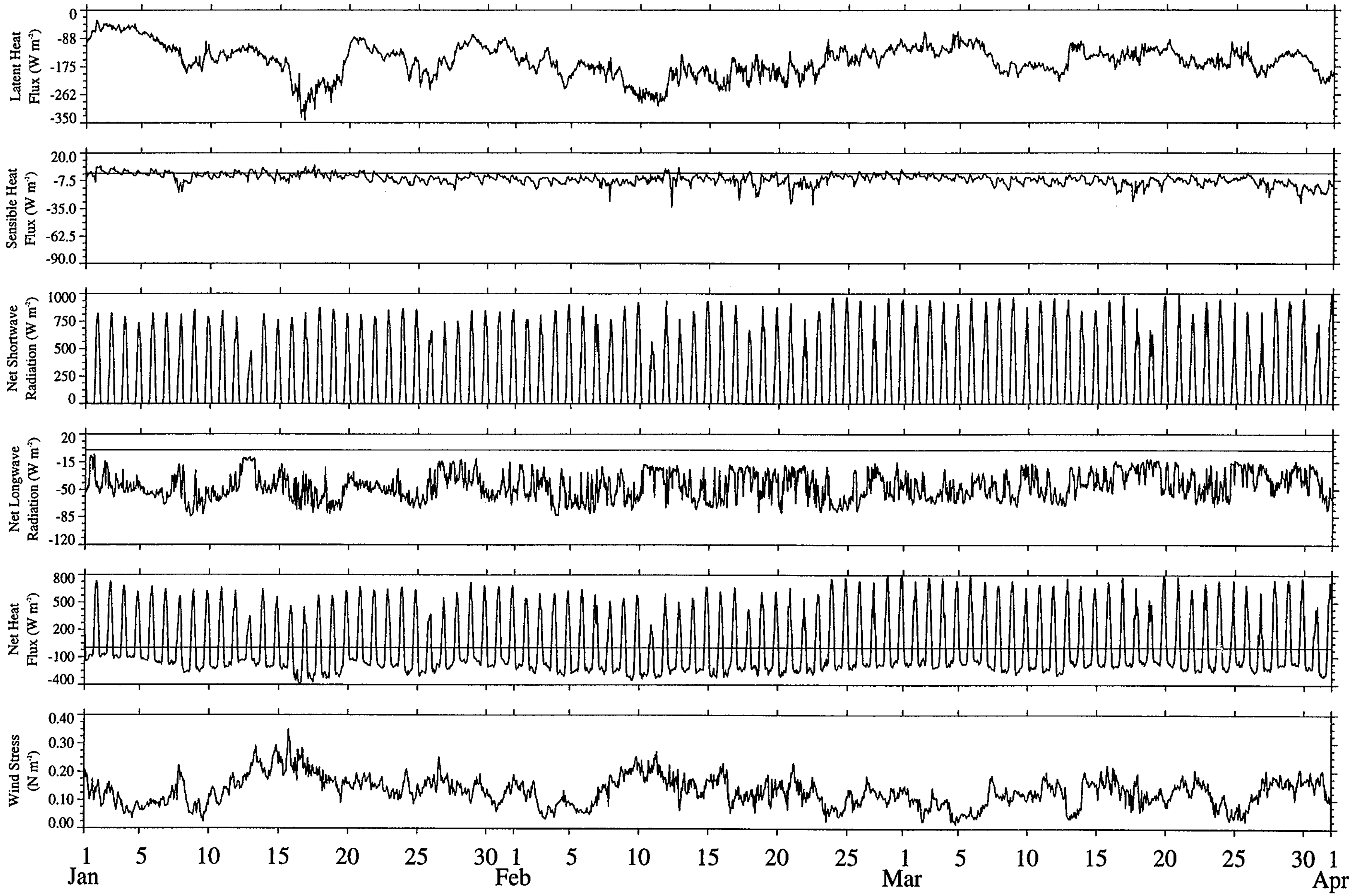


Figure 4-13. Hourly time series of estimated heat and momentum fluxes for January through March 1998. (PACS North)

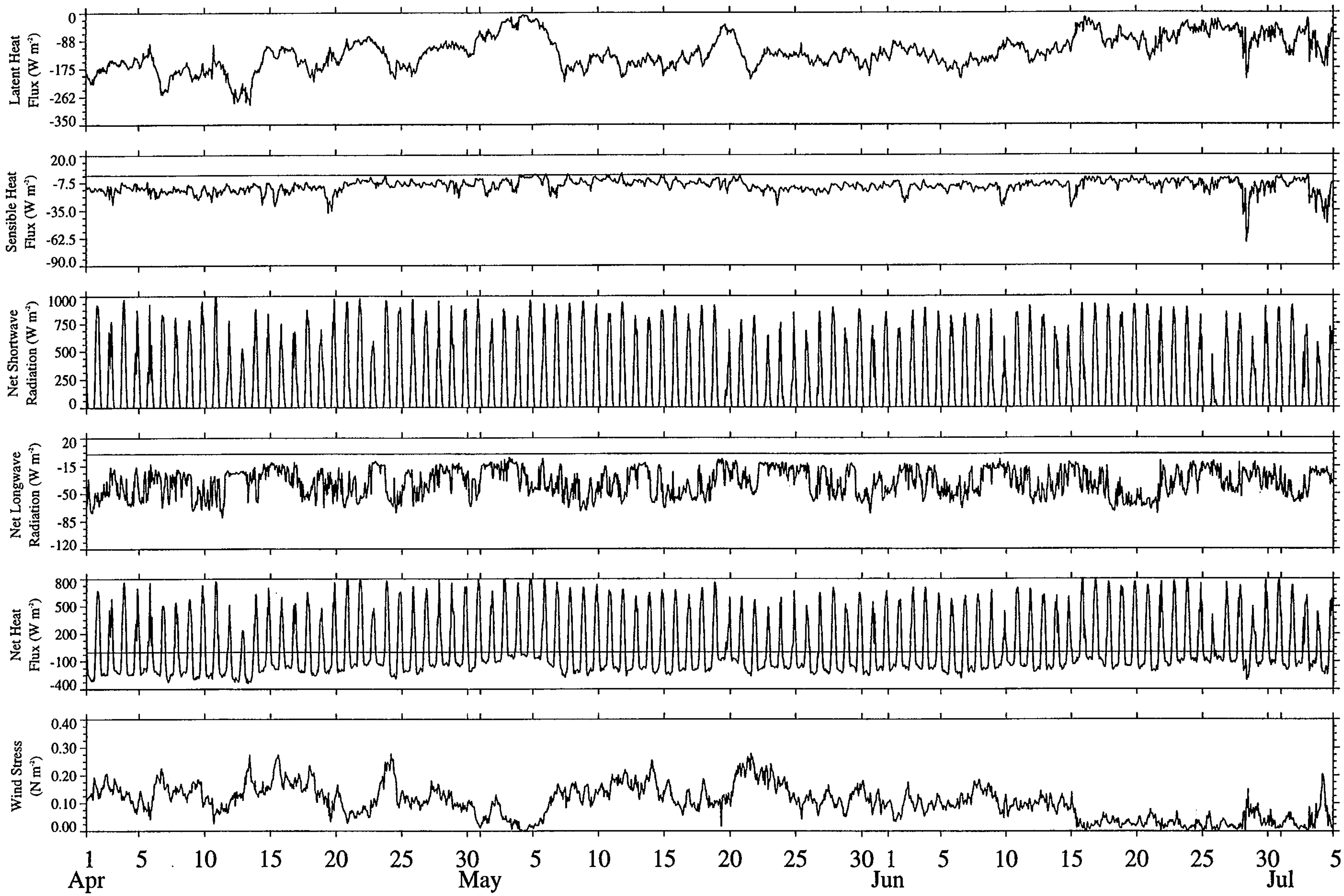


Figure 4-14. Hourly time series of estimated heat and momentum fluxes for April through June 1998.
(PACS North)

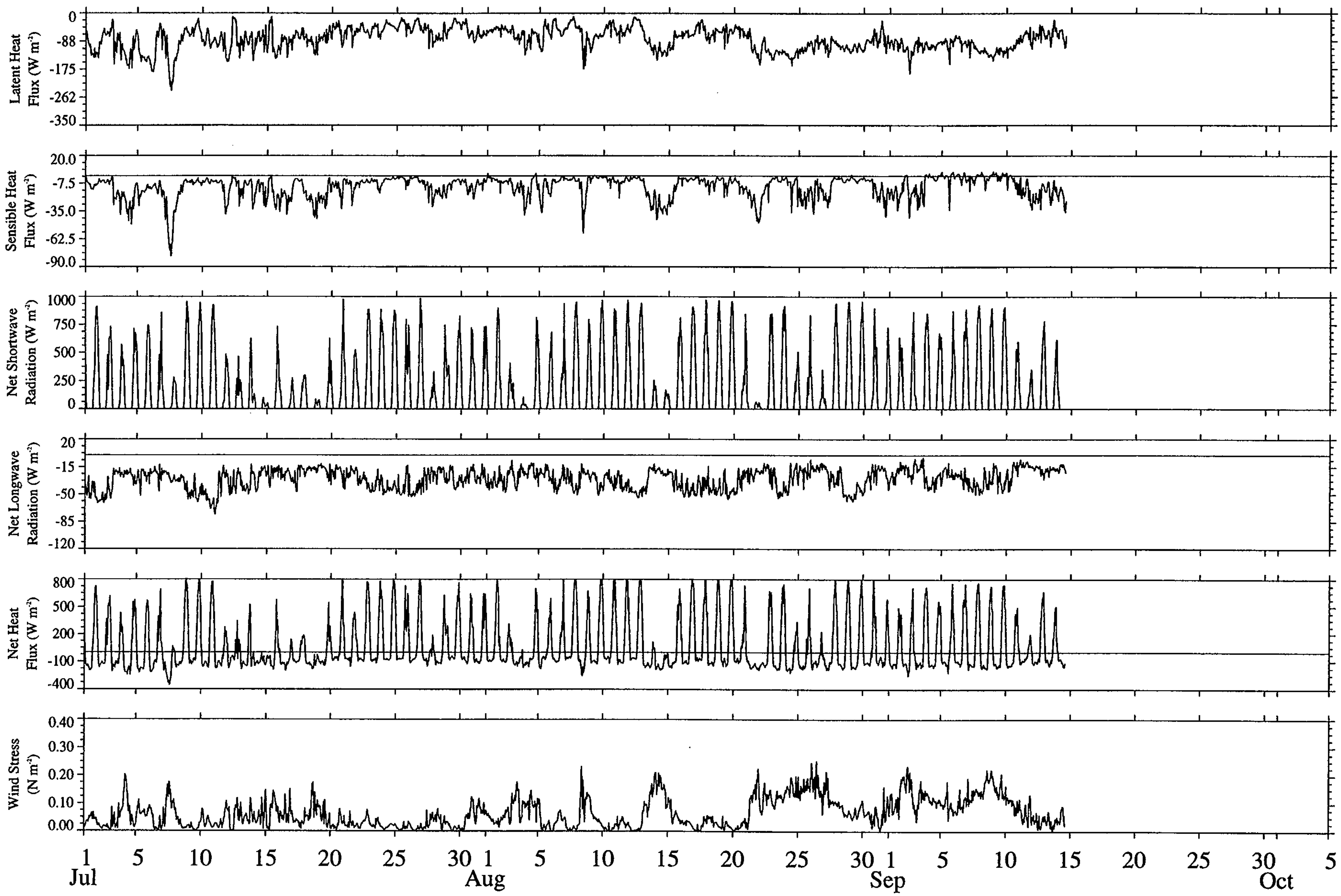


Figure 4-15. Hourly time series of estimated heat and momentum fluxes for July through September 1998.
(PACS North)

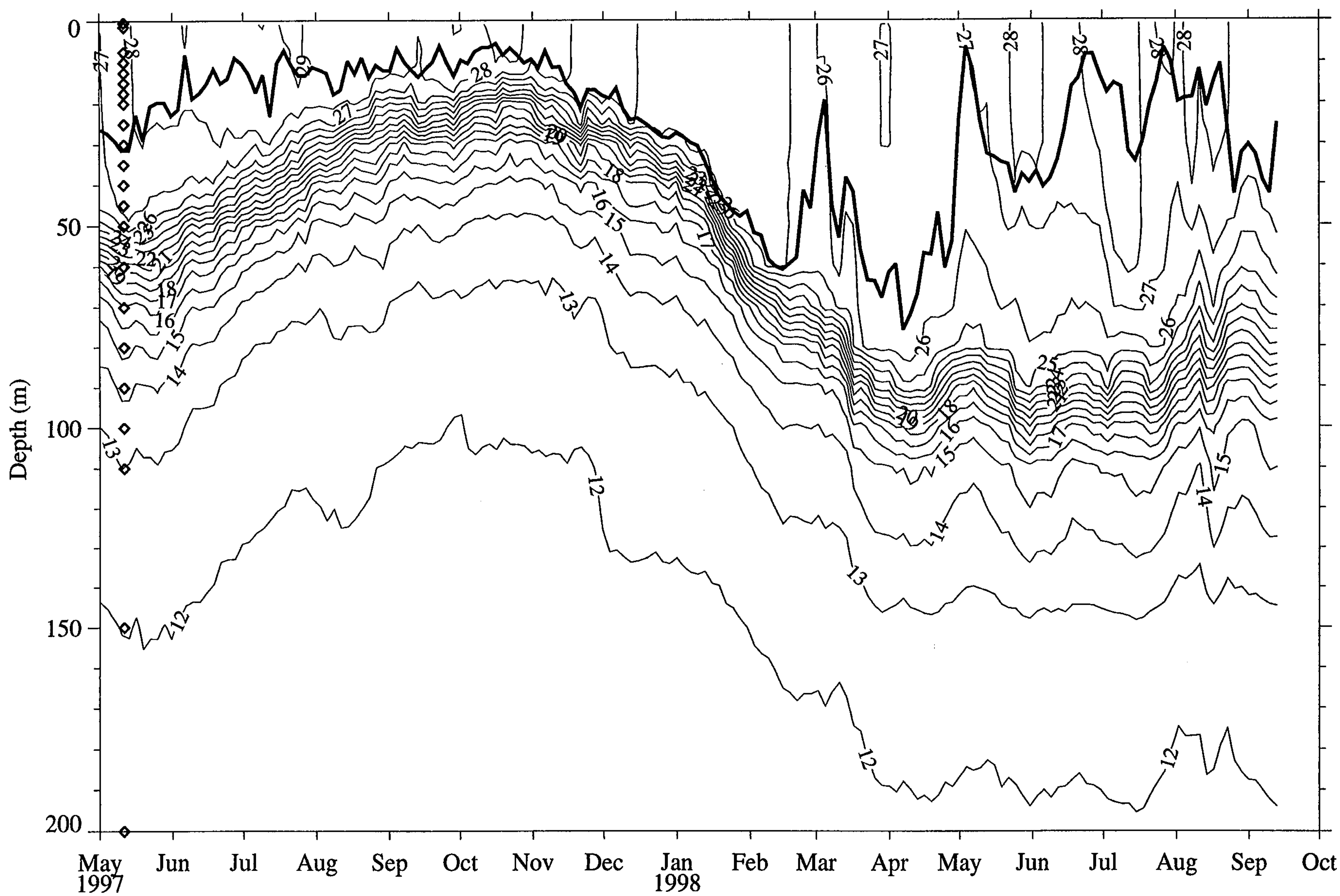


Figure 4-16. Contour plot of 36 hour averaged temperature and mixed layer depth (thick). Diamonds indicate measurement depths. Isotherms are in units of °C.

(PACS North)

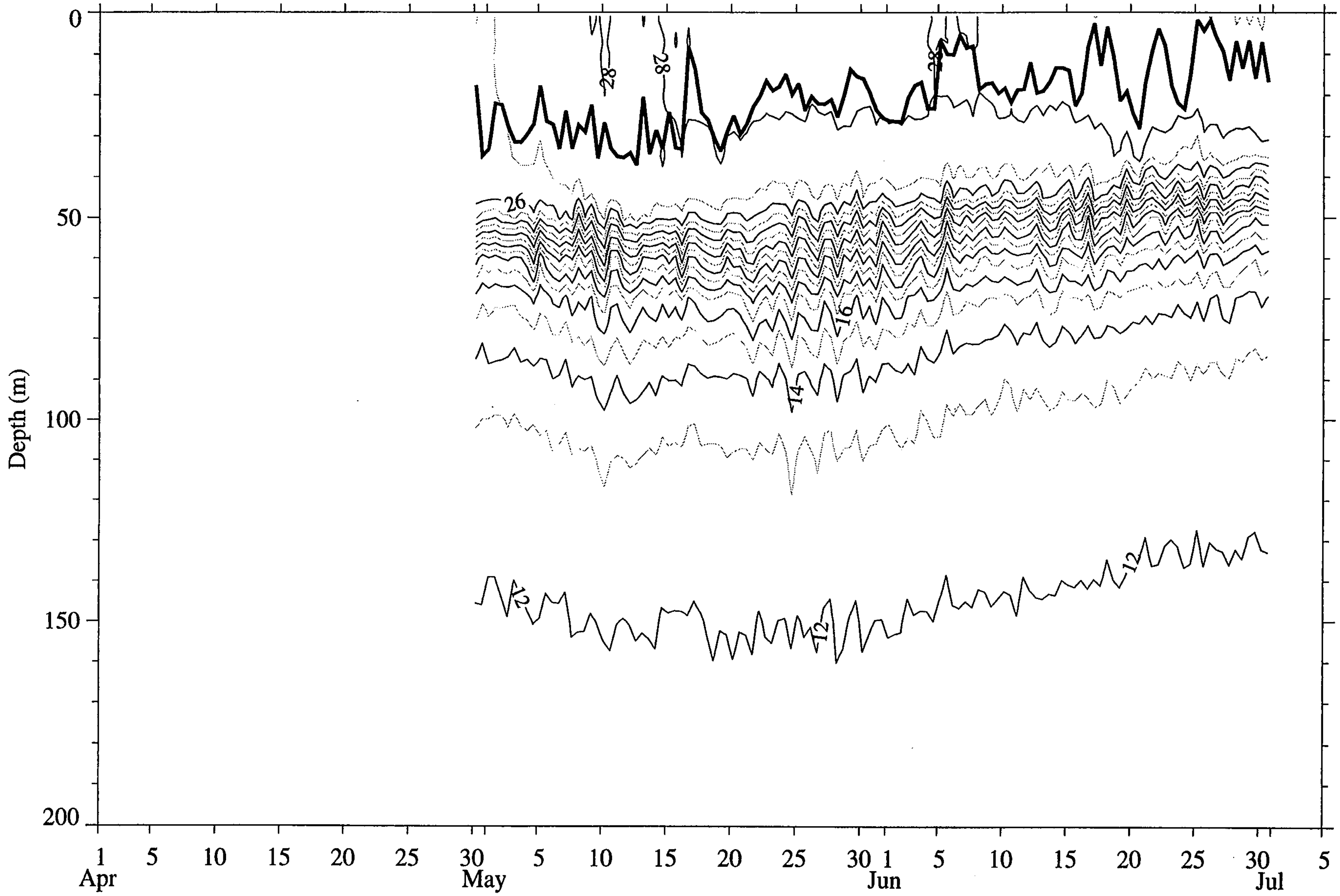


Figure 4-17. Contour plot of hourly averaged temperature and mixed layer depth (thick) for April through June 1997. Isotherms are in units of °C. (PACS North)

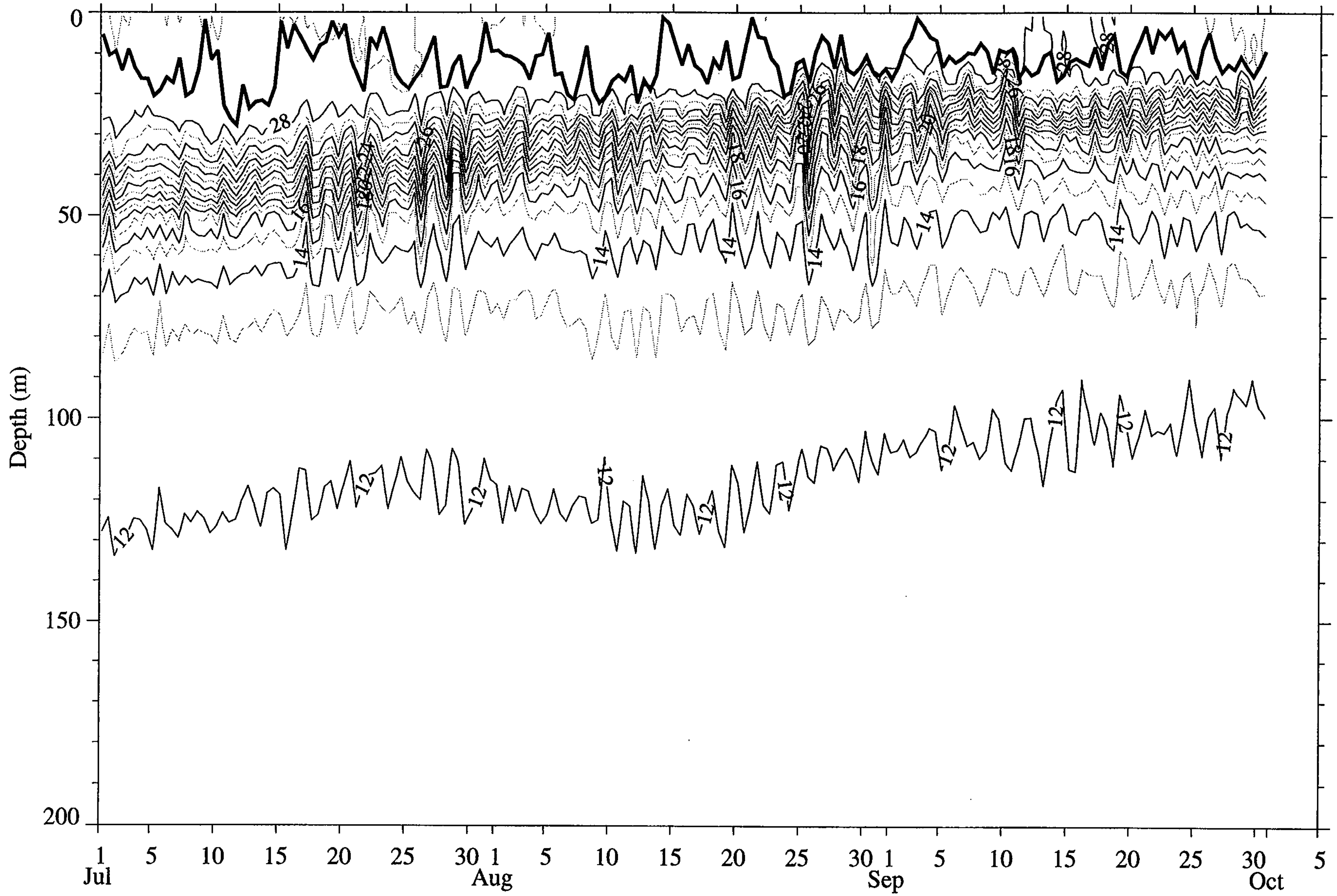


Figure 4-18. Contour plot of hourly averaged temperature and mixed layer depth (thick) for July through September 1997. Isotherms are in units of °C. (PACS North)

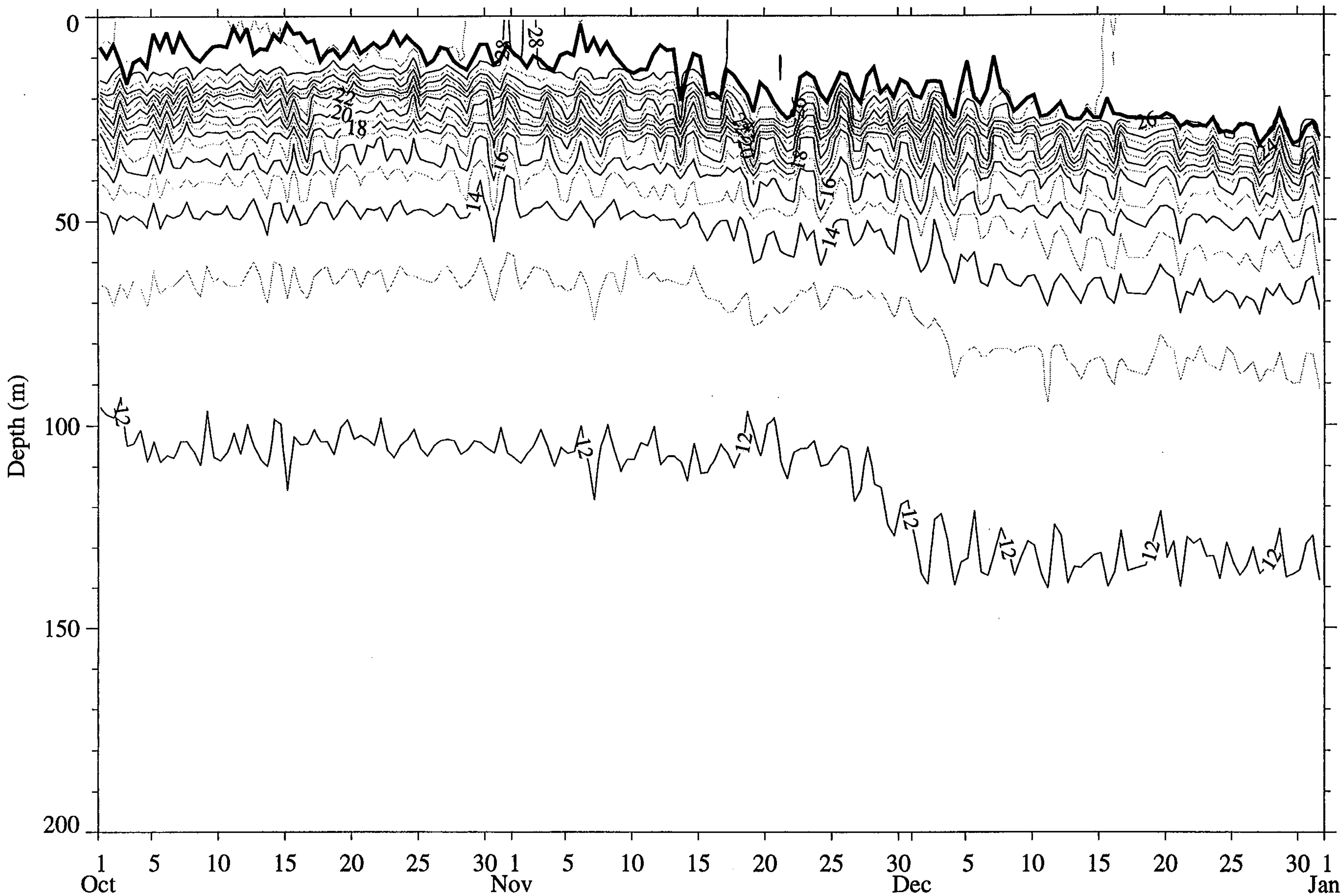


Figure 4-19. Contour plot of hourly averaged temperature and mixed layer depth (thick) for October through December 1997. Isotherms are in units of °C. (PACS North)

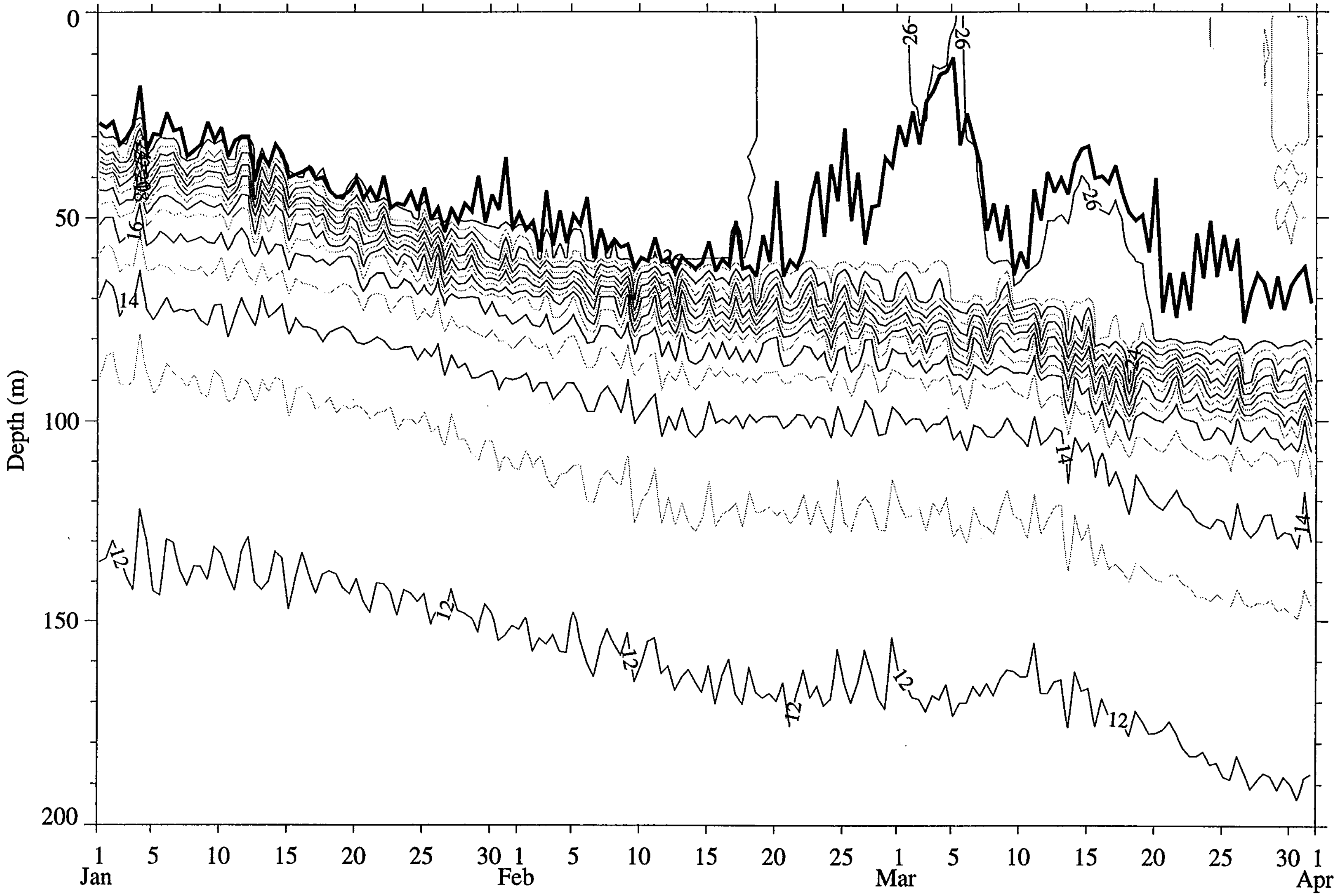


Figure 4-20. Contour plot of hourly averaged temperature and mixed layer depth (thick) for January through March 1998. Isotherms are in units of °C. (PACS North)

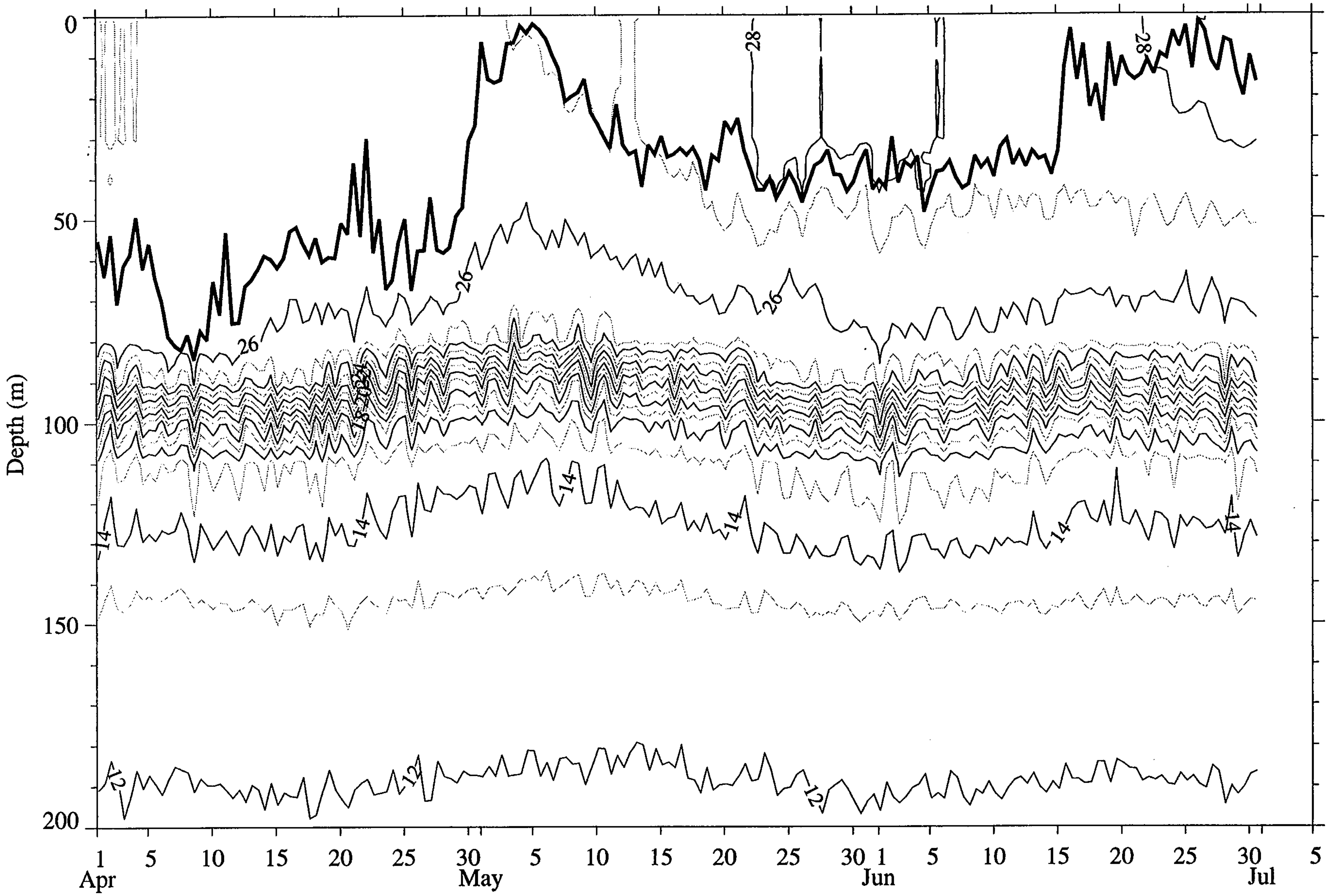


Figure 4-21. Contour plot of hourly averaged temperature and mixed layer depth (thick) for April through June 1998. Isotherms are in units of °C. (PACS North)

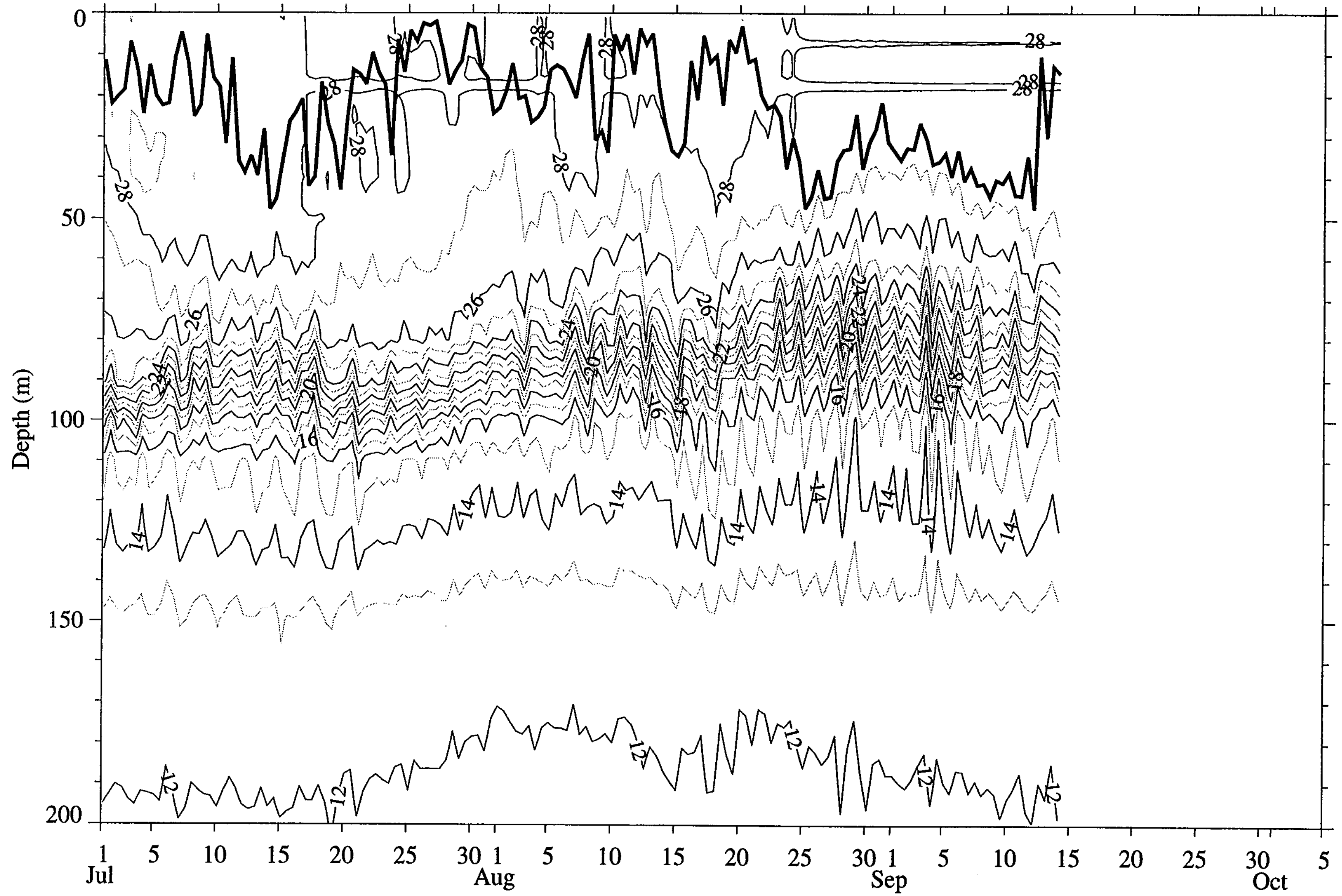


Figure 4-22. Contour plot of hourly averaged temperature and mixed layer depth (thick) for July through September 1998. Isotherms are in units of °C. (PACS North)

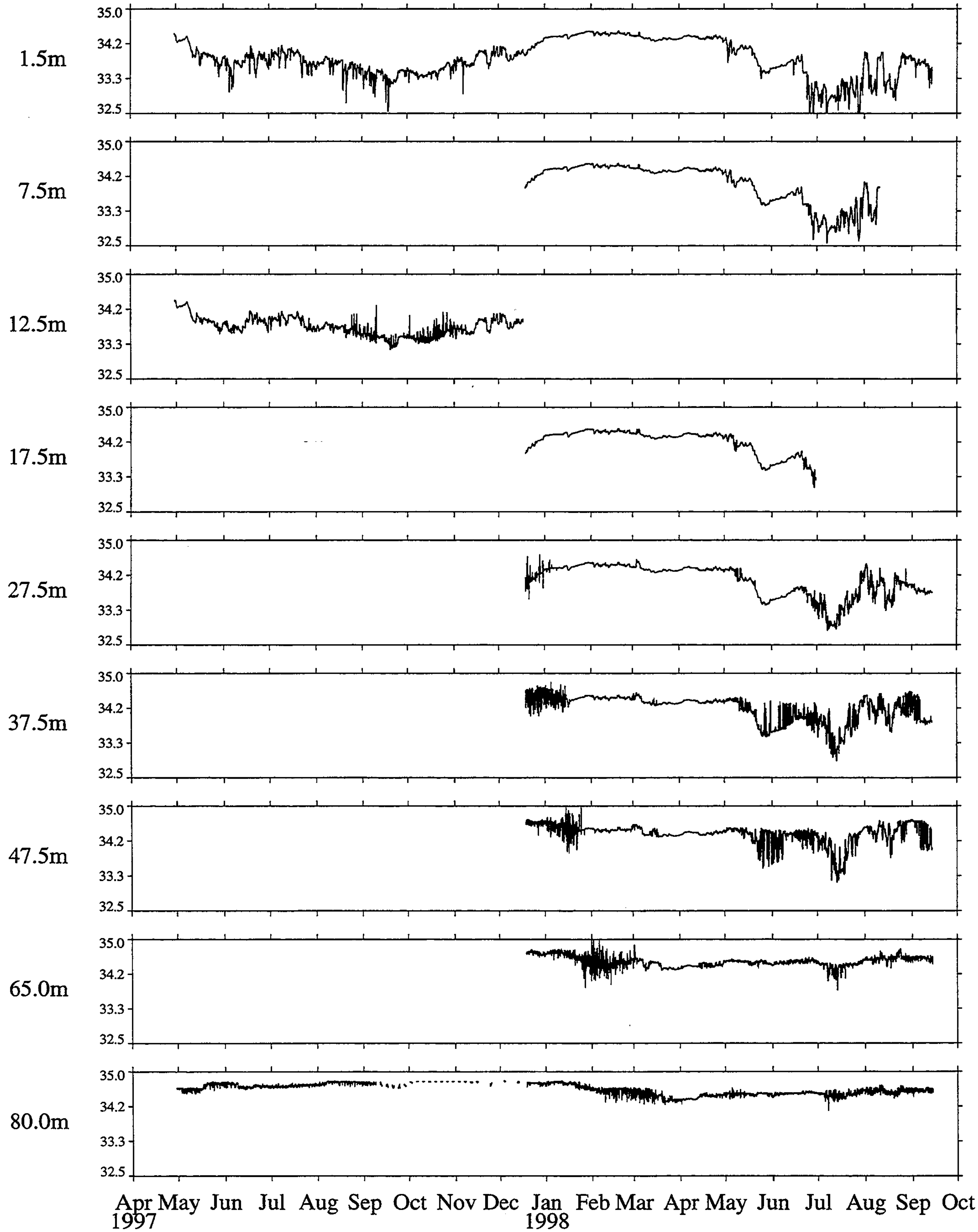


Figure 4-23. One hour salinity in PSU at selected depths.
(PACS North)

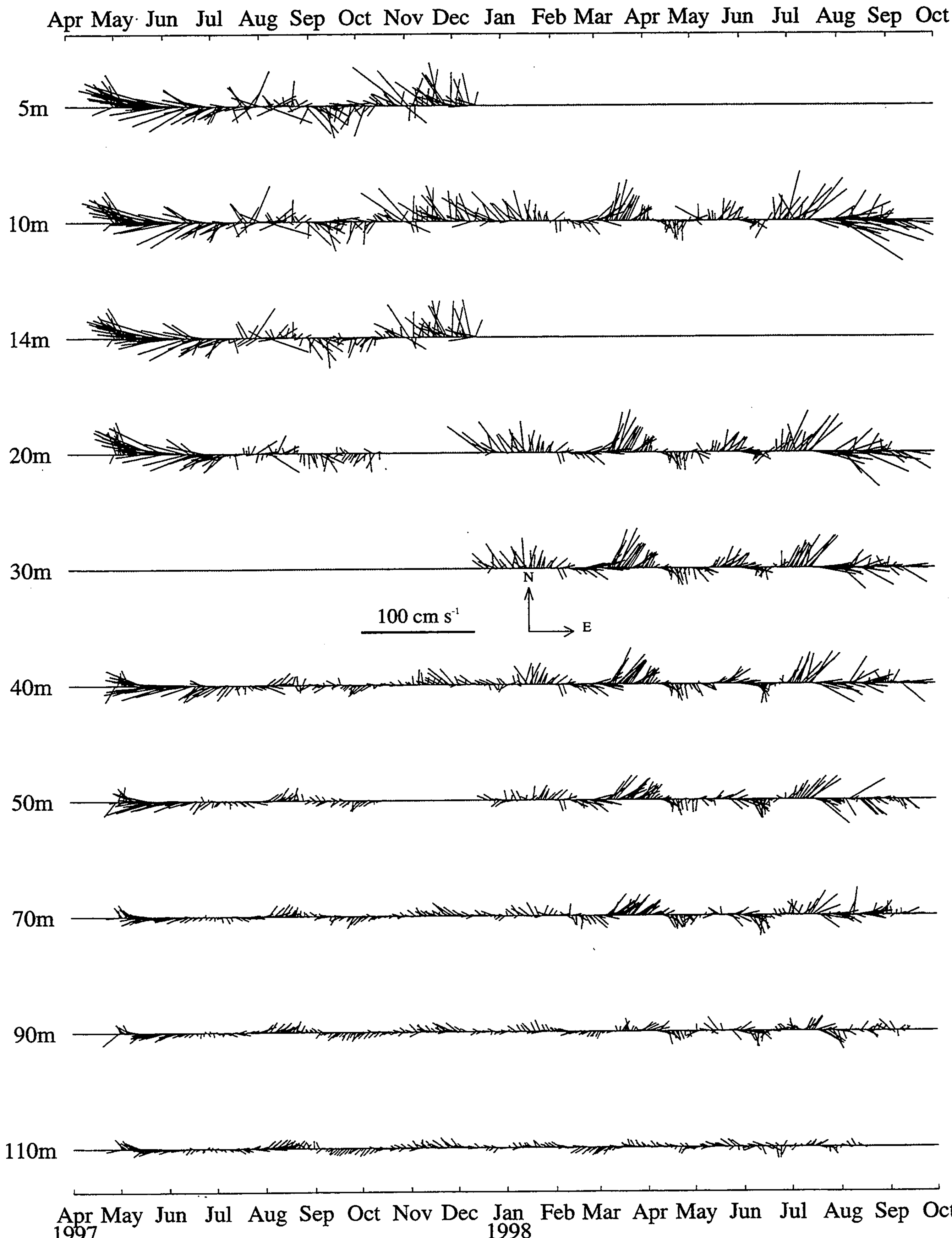


Figure 4-24. VMCM 36 hour vector averaged velocity.
(PACS North)

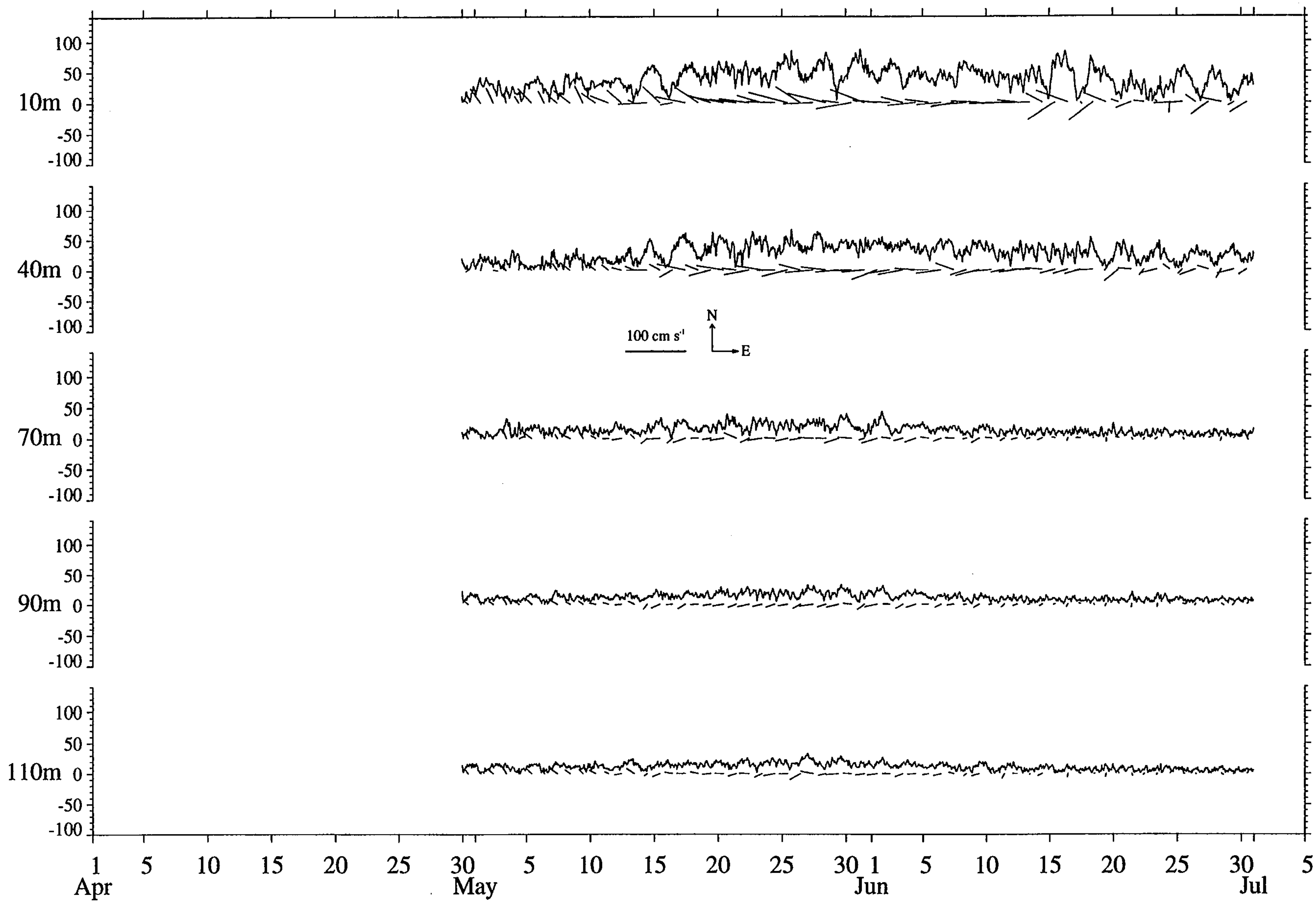


Figure 4-25. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for April through June 1997. (PACS North)

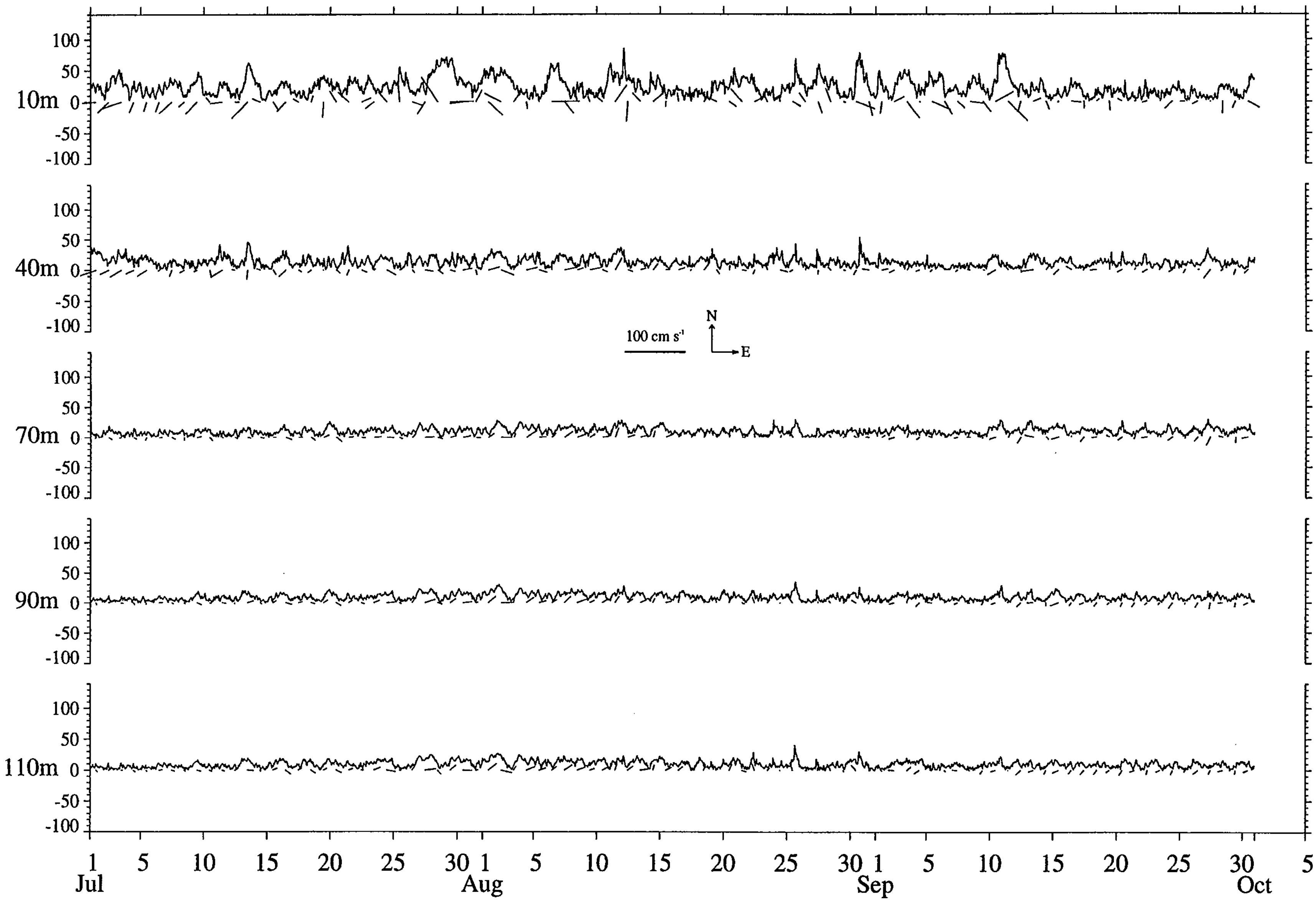


Figure 4-26. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for July through September 1997. (PACS North)

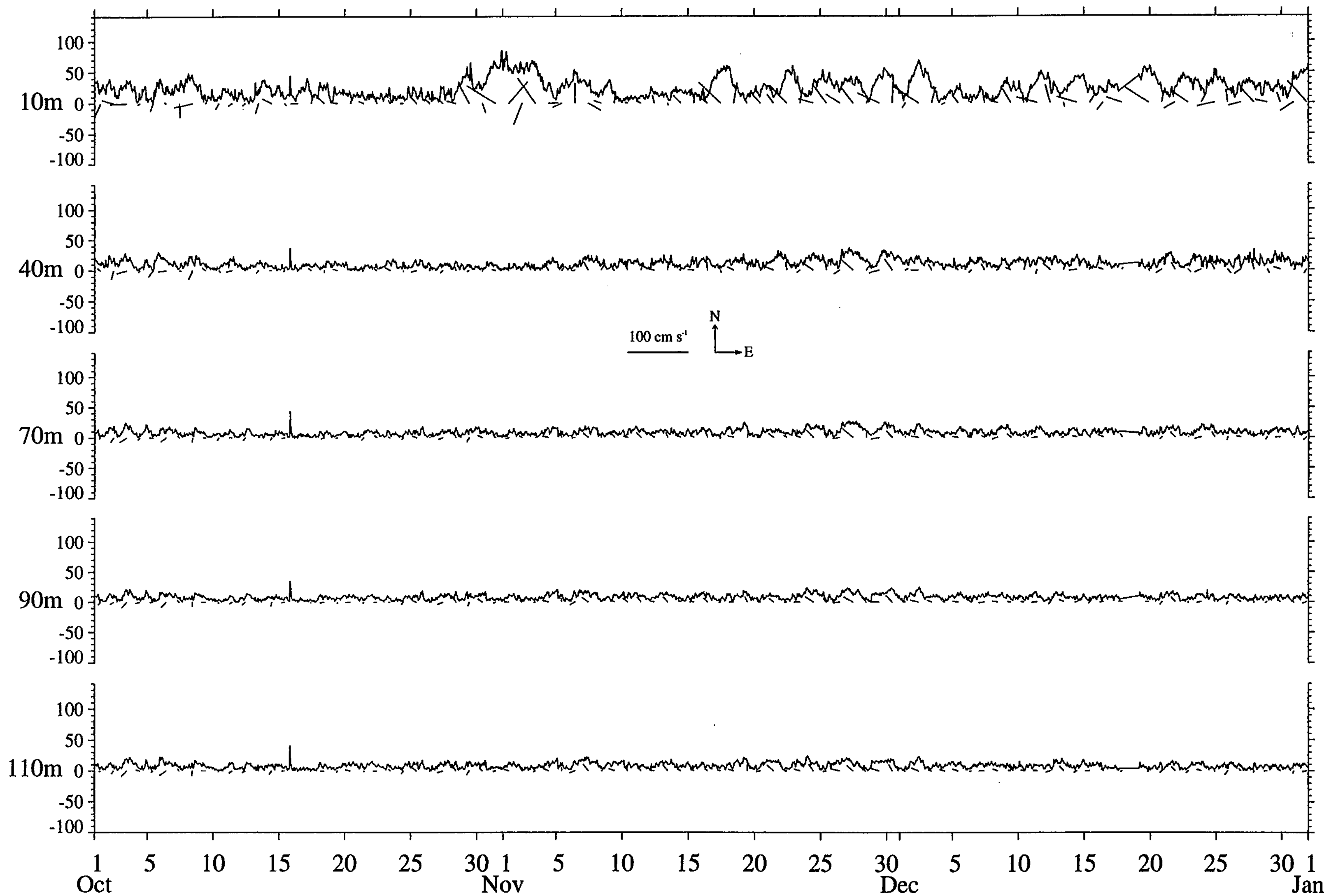


Figure 4-27. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for October through December 1997. (PACS North)

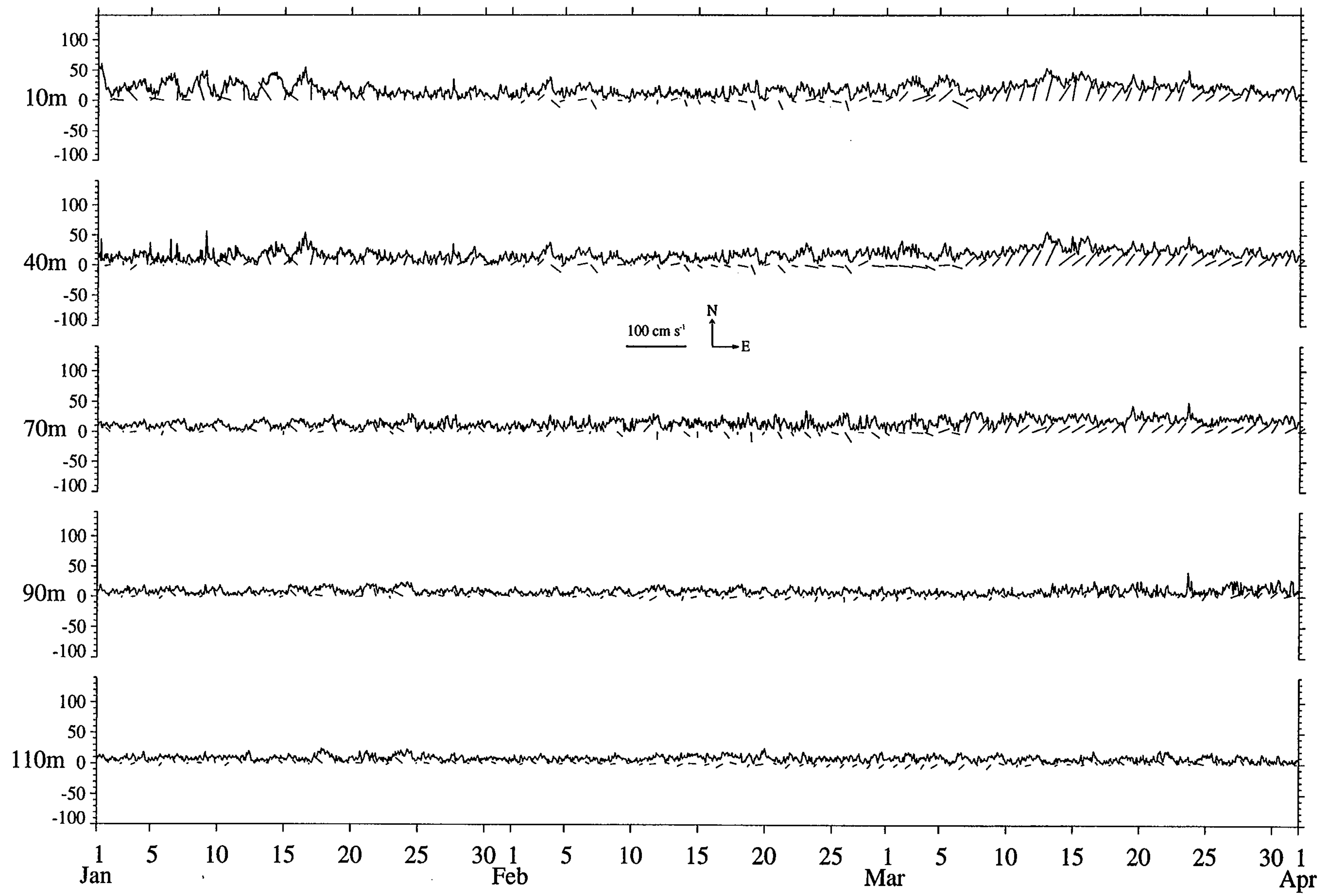


Figure 4-28. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for January through March 1998. (PACS North)

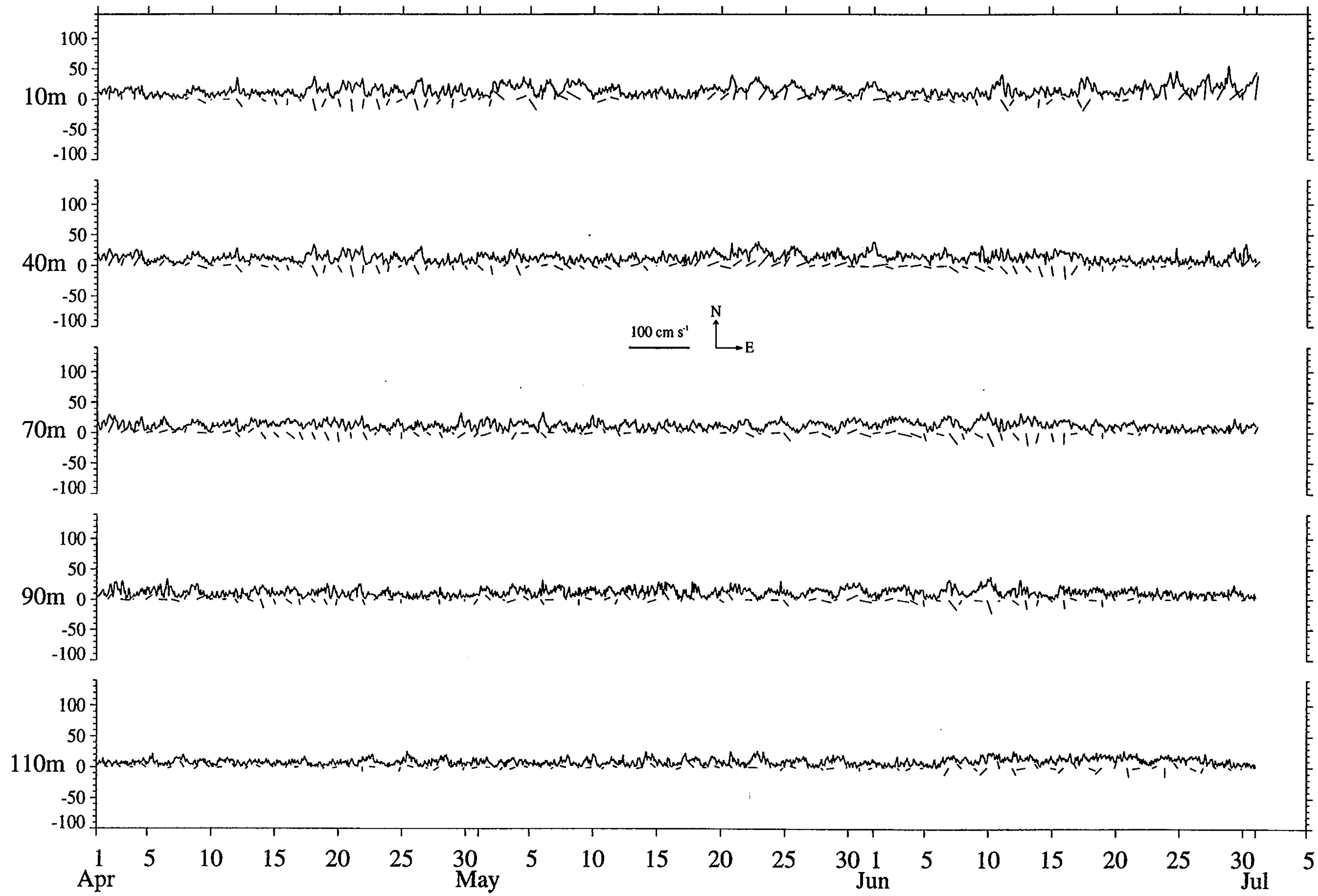


Figure 4-29. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for April through June 1998. (PACS North)

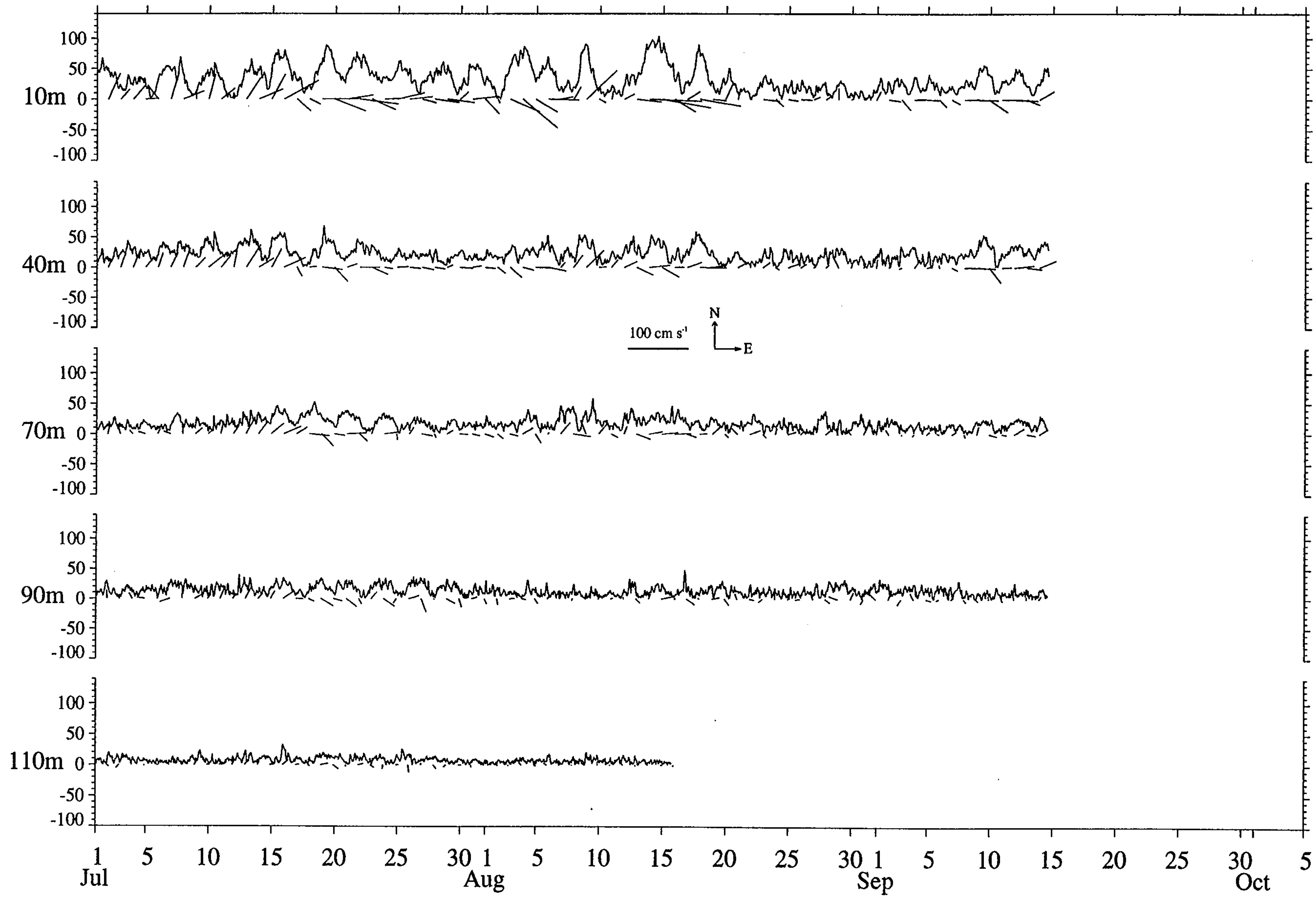


Figure 4-30. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for July through September 1998. (PACS North)

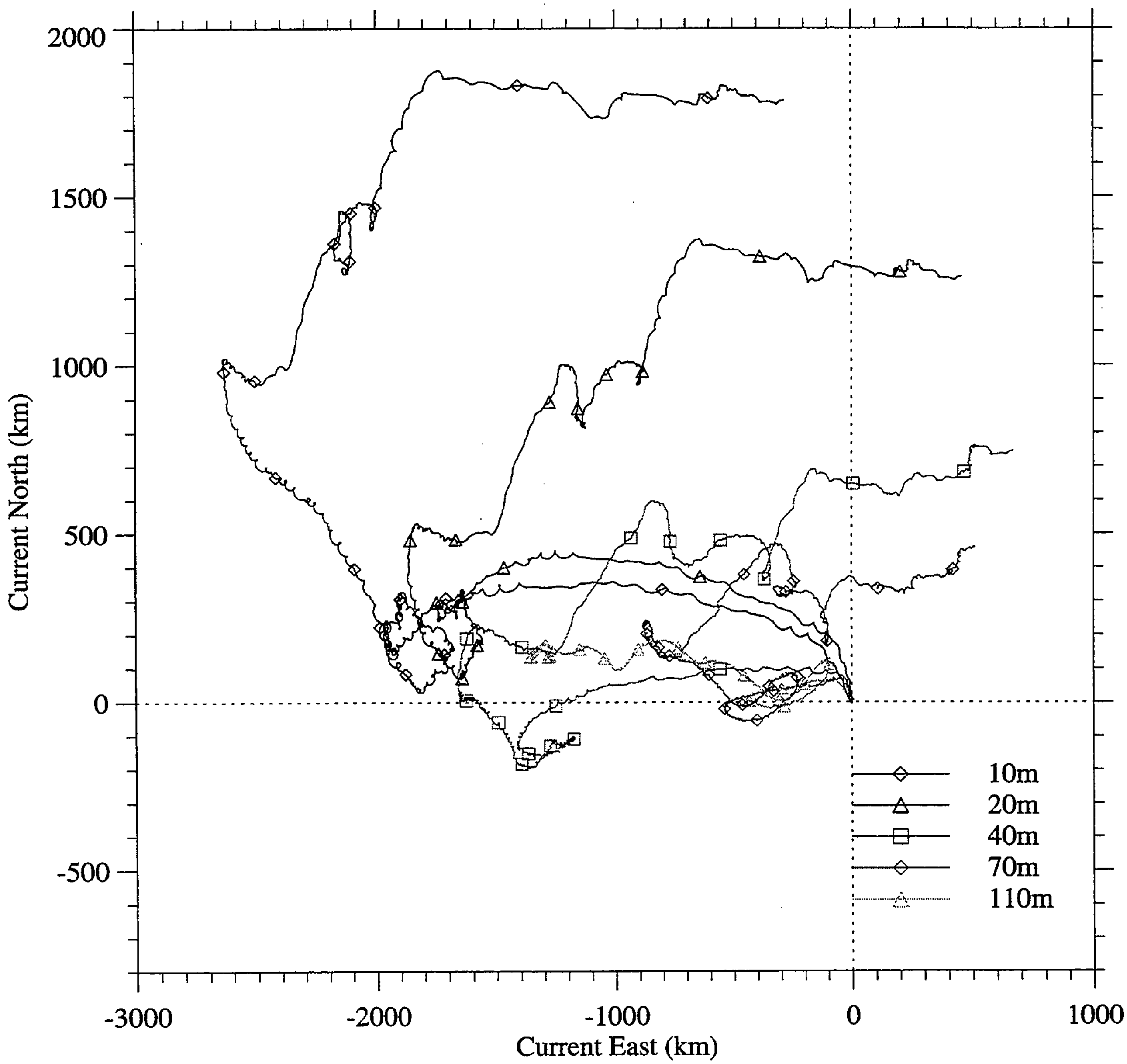


Figure 4-31. Progressive vectors from VMCM current meters. Symbols are placed 30 days apart. (PACS North)

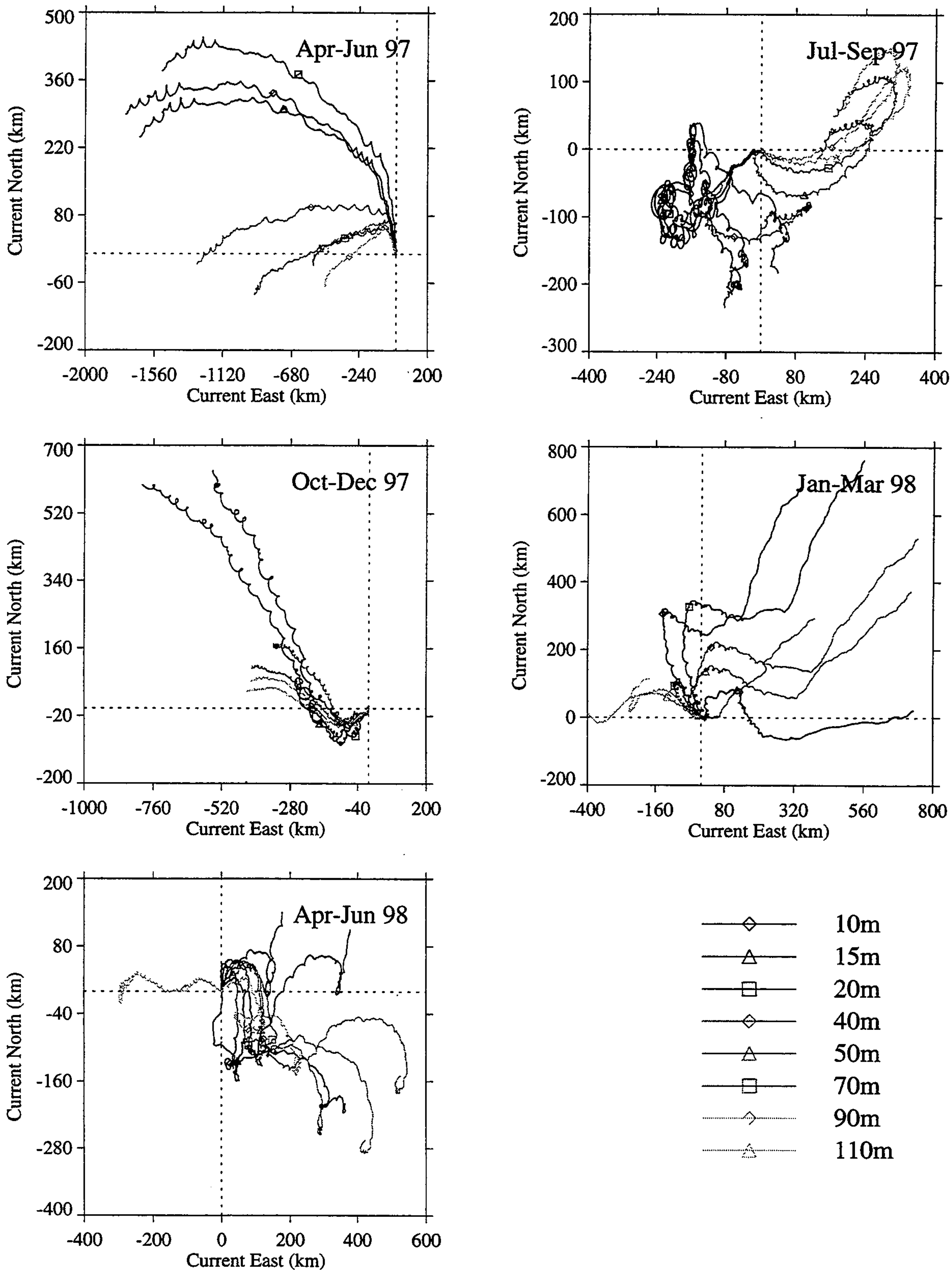


Figure 4-32. Progressive vectors from VMCM current meters. Symbols are placed 5 days apart. (PACS North)

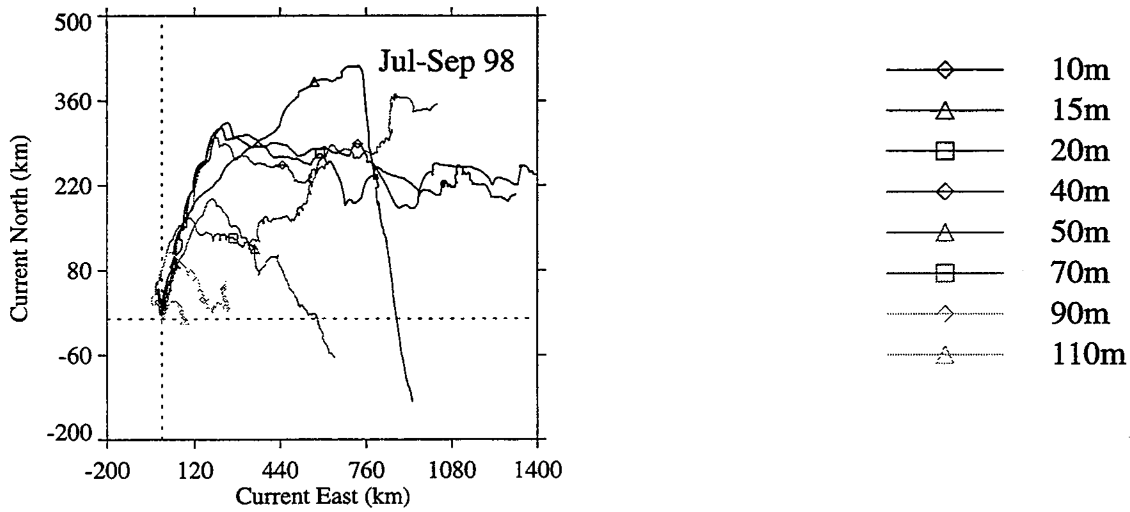


Figure 4-32. (continued)
(PACS North)

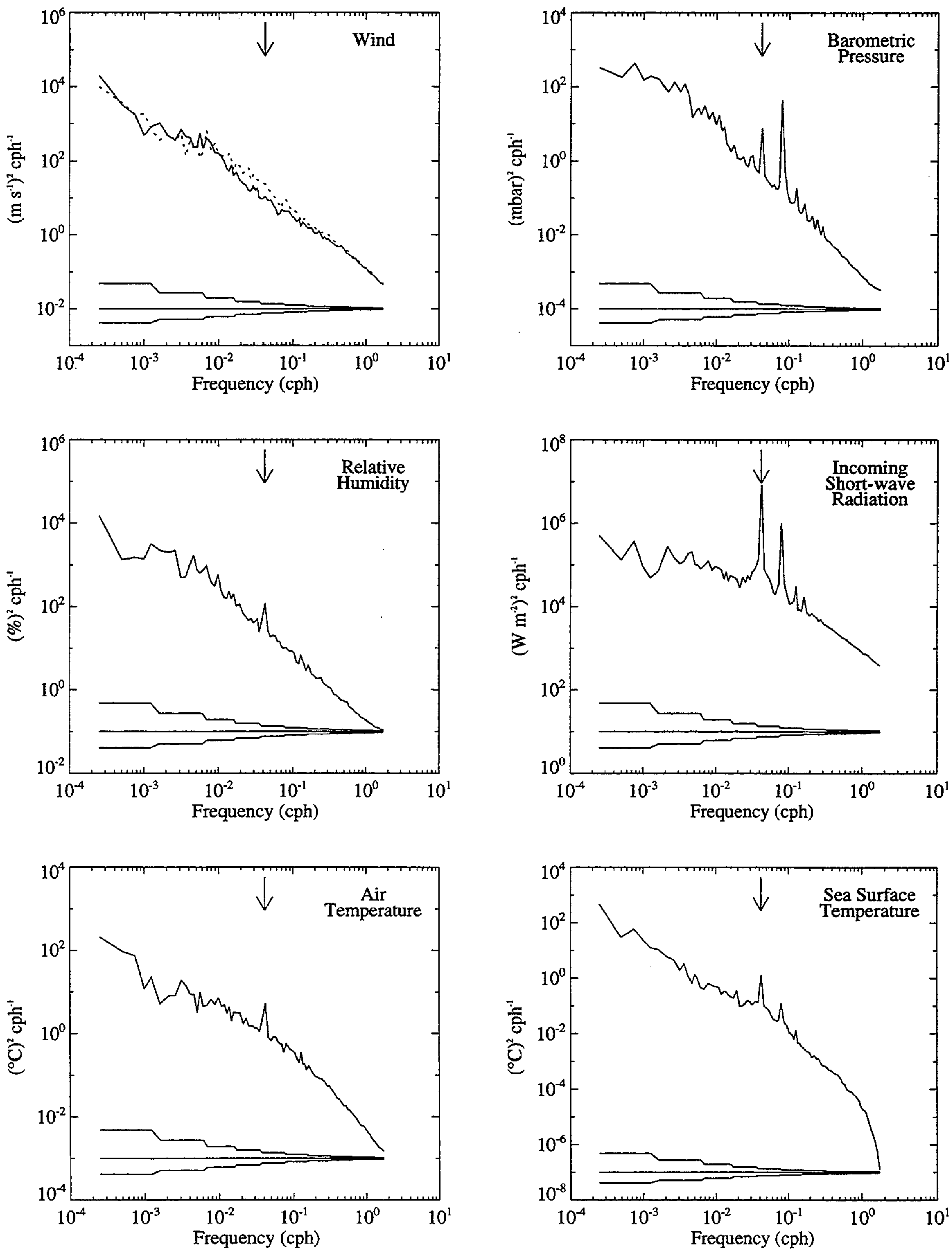


Figure 4-33. Autospectra of meteorological parameters. Rotary autospectra of the wind provides both clockwise (solid) and counter-clockwise (dotted) spectras. The arrow indicates the diurnal frequency (24^{-1} cph).

(PACS North)

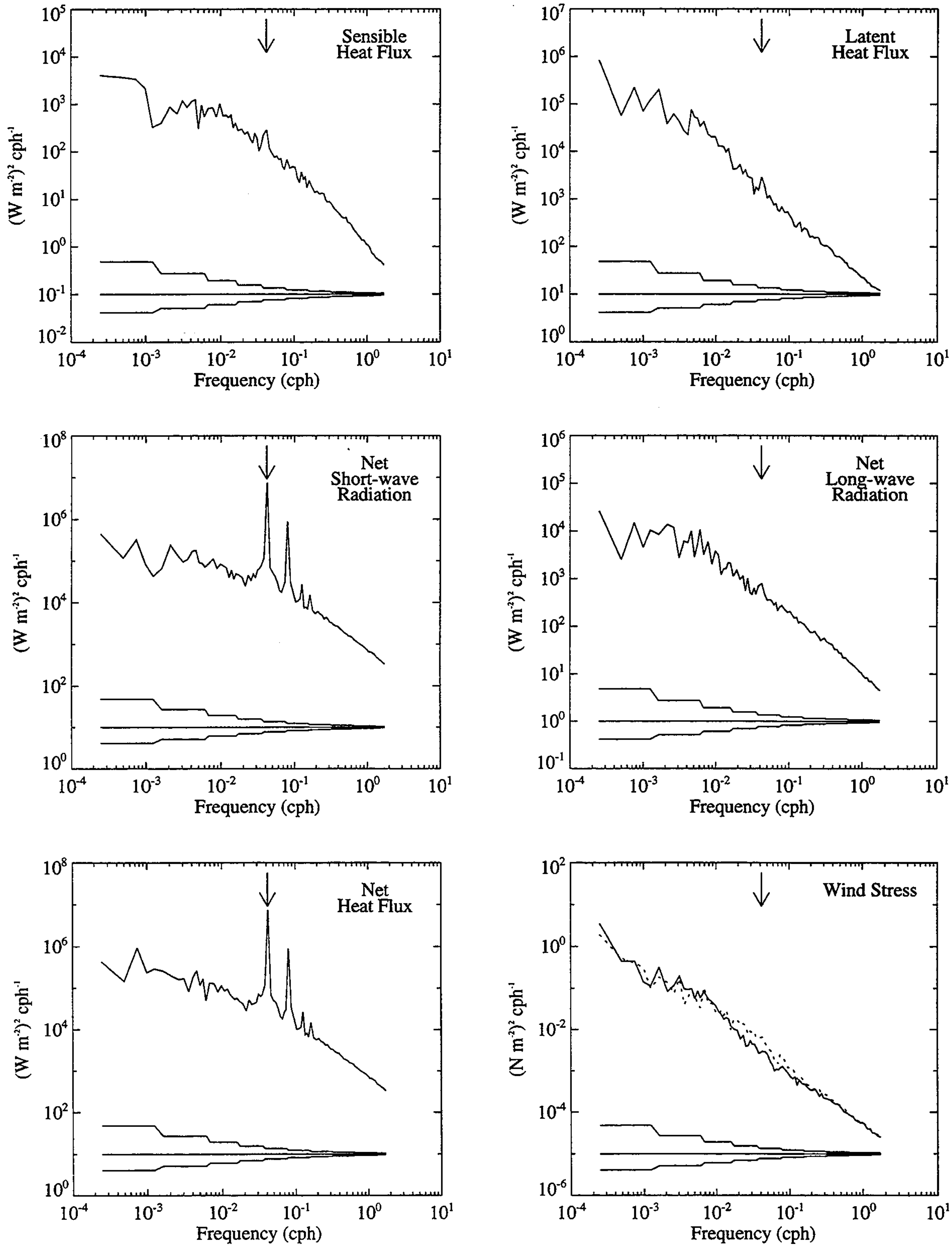


Figure 4-34. Autospectra of heat fluxes. Rotary autospectra of the wind stress provides both clockwise (solid) and counter-clockwise (dotted) spectras. The arrow indicates the diurnal frequency (24^{-1} cph).

(PACS North)

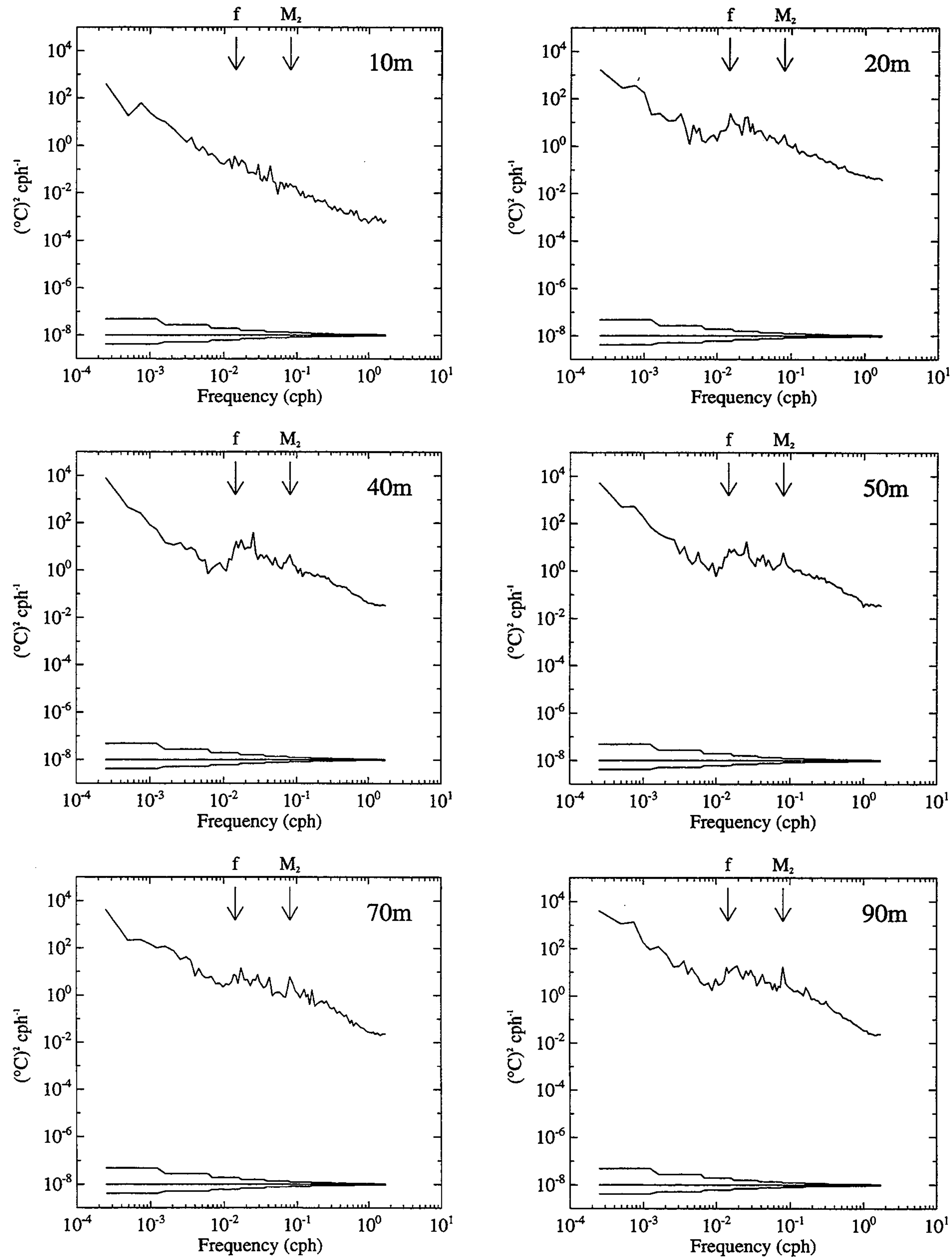


Figure 4-35. Autospectra of temperature at various depths. The tidal M_2 and inertial frequencies are indicated with arrows.

(PACS North)

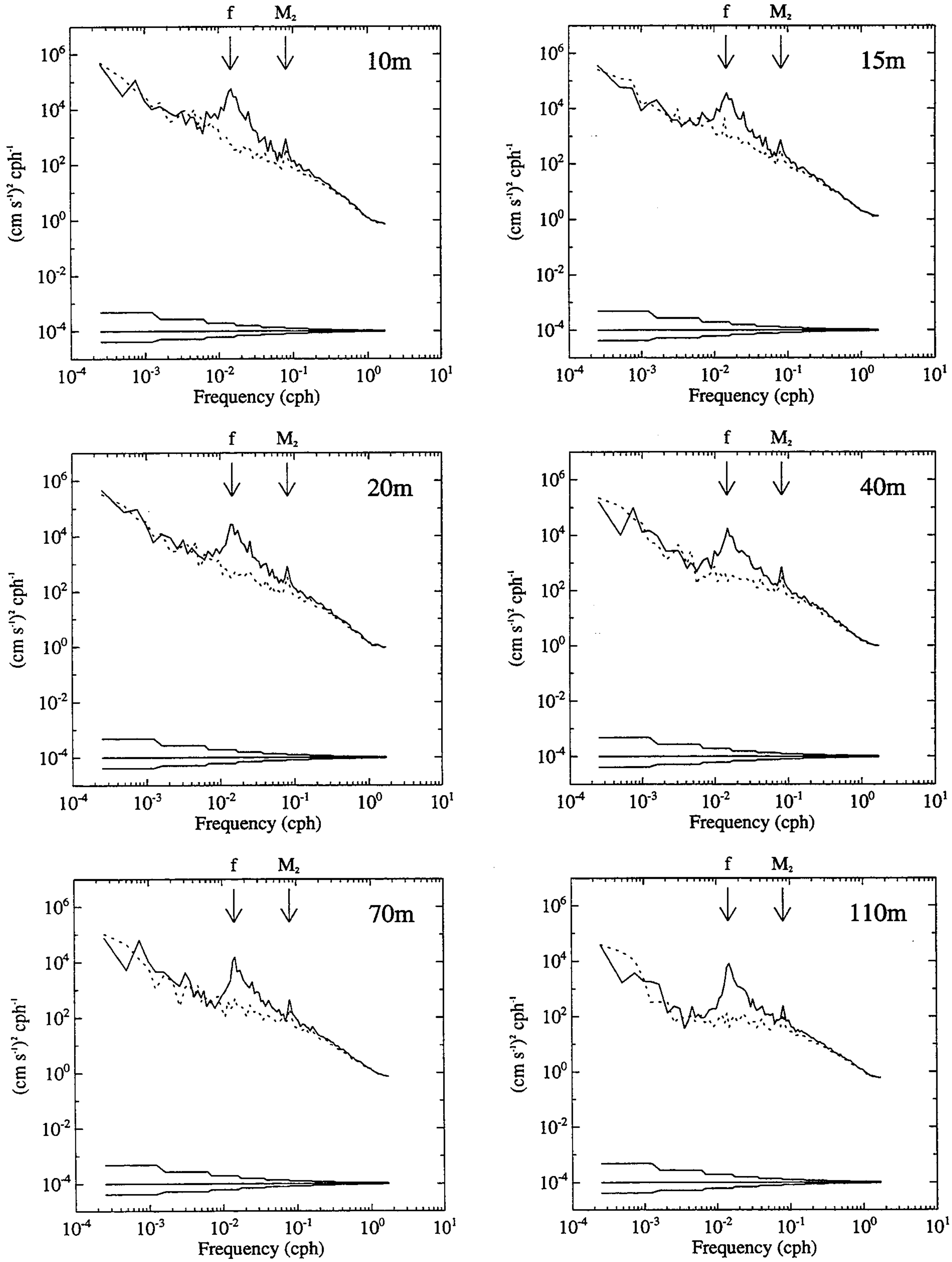


Figure 4-36. Rotary autospectra of velocity at various depths. The tidal M_2 and inertial frequencies are indicated with arrows. Clockwise spectra are solid and counter-clockwise spectra are dotted.

(PACS North)

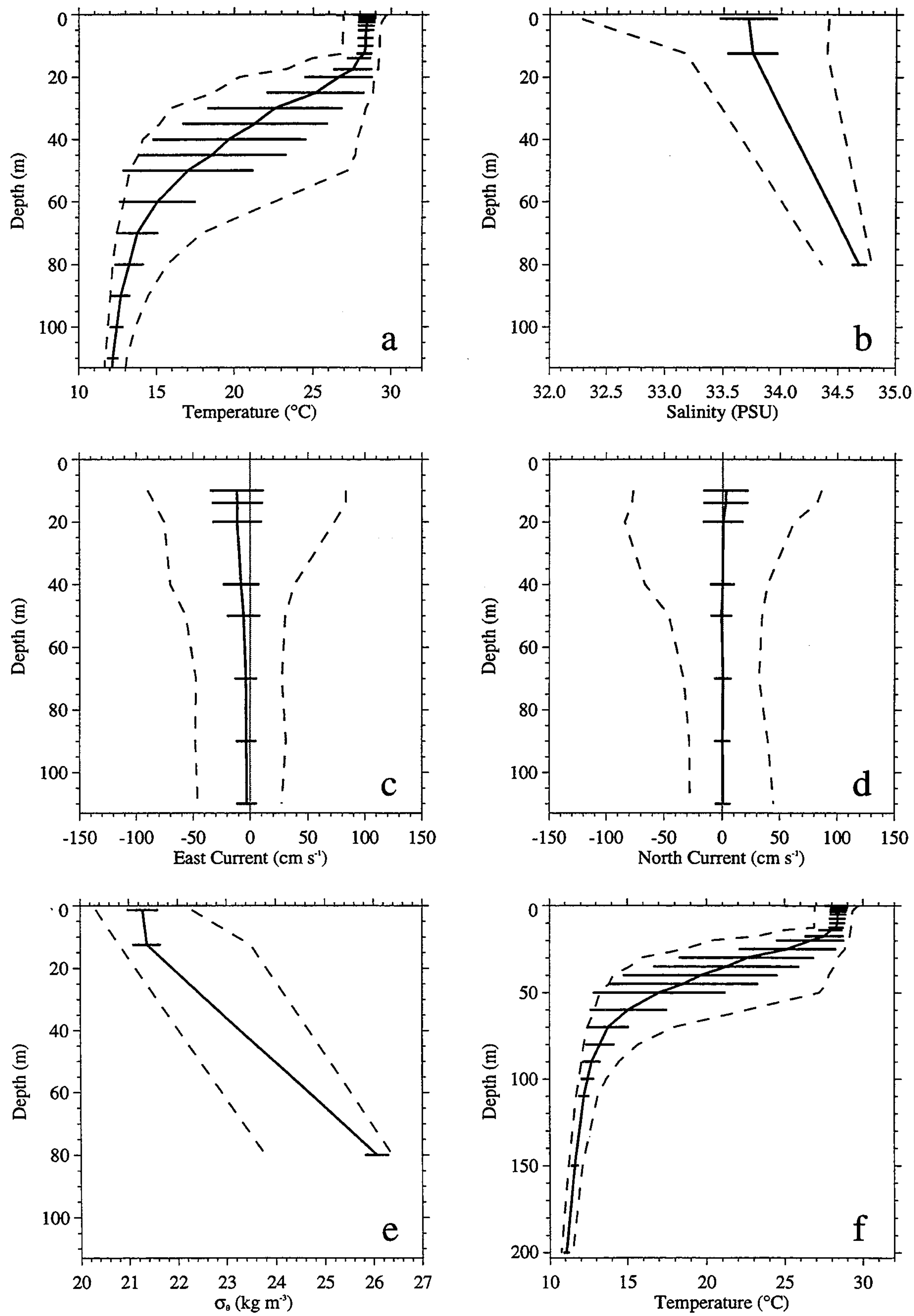


Figure 4-37. Mean profiles of April 1997 to December 1997 (horizontal bar indicates ± standard deviation, dash line indicates maximum and minimum range). (PACS North)

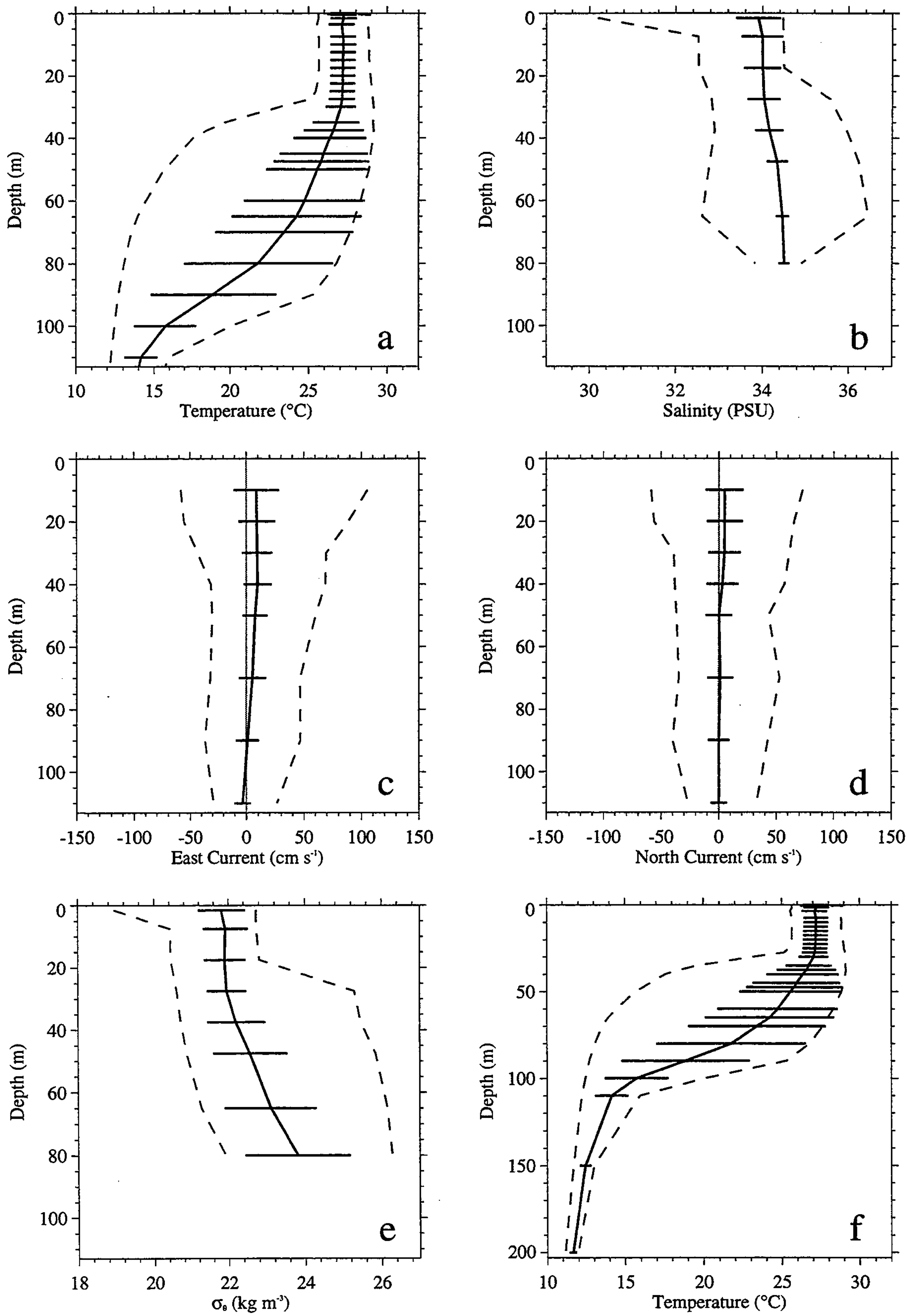


Figure 4-38. Mean profiles of December 1997 to September 1998 (horizontal bar indicates ± standard deviation, dash line indicates maximum and minimum range). (PACS North)

Section 5: PACS South Statistics and Plots

Statistics of the meteorological measurements and estimated heat, momentum and freshwater fluxes for the 17 month long experiment are presented in Table 5-1 for PACS South. Each table contains the mean, standard deviation, minimum and maximum of the meteorological measurements and fluxes. Meteorological observations are presented next followed by precipitation, heat and flux time series, contours of subsurface temperatures with mixed layer depth (the mixed layer depth in these plots was computed as the depth at which the temperature differs from the sea surface temperature (measured at 0.17 m) by 0.1°C), velocity stick plots with current speed overlaid, progressive vector diagrams and auto spectra for meteorological, flux, temperature and velocity variables. Band averaging was used in each of the autospectra plots and the 95% confidence limits are shown. The first 5 frequencies were averaged over 3 bands and the number of bands averaged was doubled every 10 frequencies thereafter (i.e., frequencies 6-15 were averaged over 6 bands, frequencies 16-25 were averaged over 12 bands, frequencies 26-35 were averaged over 24 bands, etc.). See the following table for the page numbers of the different plots.

Table 5-1. Statistics for Combined Met. and Air-Sea Flux Time Series for PACS South. The time period is 21/04/1997 01:30 UTC to 20/09/1998 13:30 UTC. (49686 data points)

Variable	Unit	Mean	Std Dev.	Minimum	Maximum
Air Temperature	°C	27.084	1.393	22.143	30.848
Relative Humidity	%	83.521	6.356	61.894	102.265
East Component	$m\ s^{-1}$	-3.860	2.772	-13.135	12.093
North Component	$m\ s^{-1}$	1.896	2.421	-10.924	9.061
Scalar Averaged Wind Speed	$m\ s^{-1}$	5.344	2.028	0.000	14.027
Short-wave Radiation	$W\ m^{-2}$	242.845	332.603	0.004	1274.840
Long-wave Radiation	$W\ m^{-2}$	415.613	21.773	363.308	499.332
Barometric Pressure	mbar	1010.498	2.180	1003.211	1017.164
Sea Temperature at 0.25m	°C	27.693	1.689	23.193	31.857
Sea Temperature at 5.0m	°C	27.734	1.677	23.257	30.447
Specific Humidity	g/kg	18.432	1.163	14.486	21.607
Precipitation Rate	$mm\ hr^{-1}$	0.157	1.645	-21.101	64.880
Evaporation Rate	$mm\ hr^{-1}$	-0.143	0.081	-0.629	0.002
Wind Stress Magnitude	$N\ m^{-2}$	0.055	0.042	0.000	0.461
Sensible Heat Flux	$W\ m^{-2}$	-3.623	6.587	-67.431	12.336
Latent Heat Flux	$W\ m^{-2}$	-96.481	54.542	-425.610	1.081
Net Short-wave Radiation	$W\ m^{-2}$	229.488	314.310	0.004	1204.724
Net Long-wave Radiation	$W\ m^{-2}$	-46.493	17.651	-98.921	27.884
Net Heat Flux	$W\ m^{-2}$	82.853	315.459	-399.289	1097.355
Skin Temperature	°C	27.528	1.660	23.136	36.230
Wind Speed At 10m [a]	$m\ s^{-1}$	5.801	2.309	0.106	15.529
Air Temperature 2m [a]	°C	27.068	1.389	22.117	30.811
Relative Humidity2m [a]	%	45.895	30.343	15.395	98.348

([a]) estimated from boundary layer profile

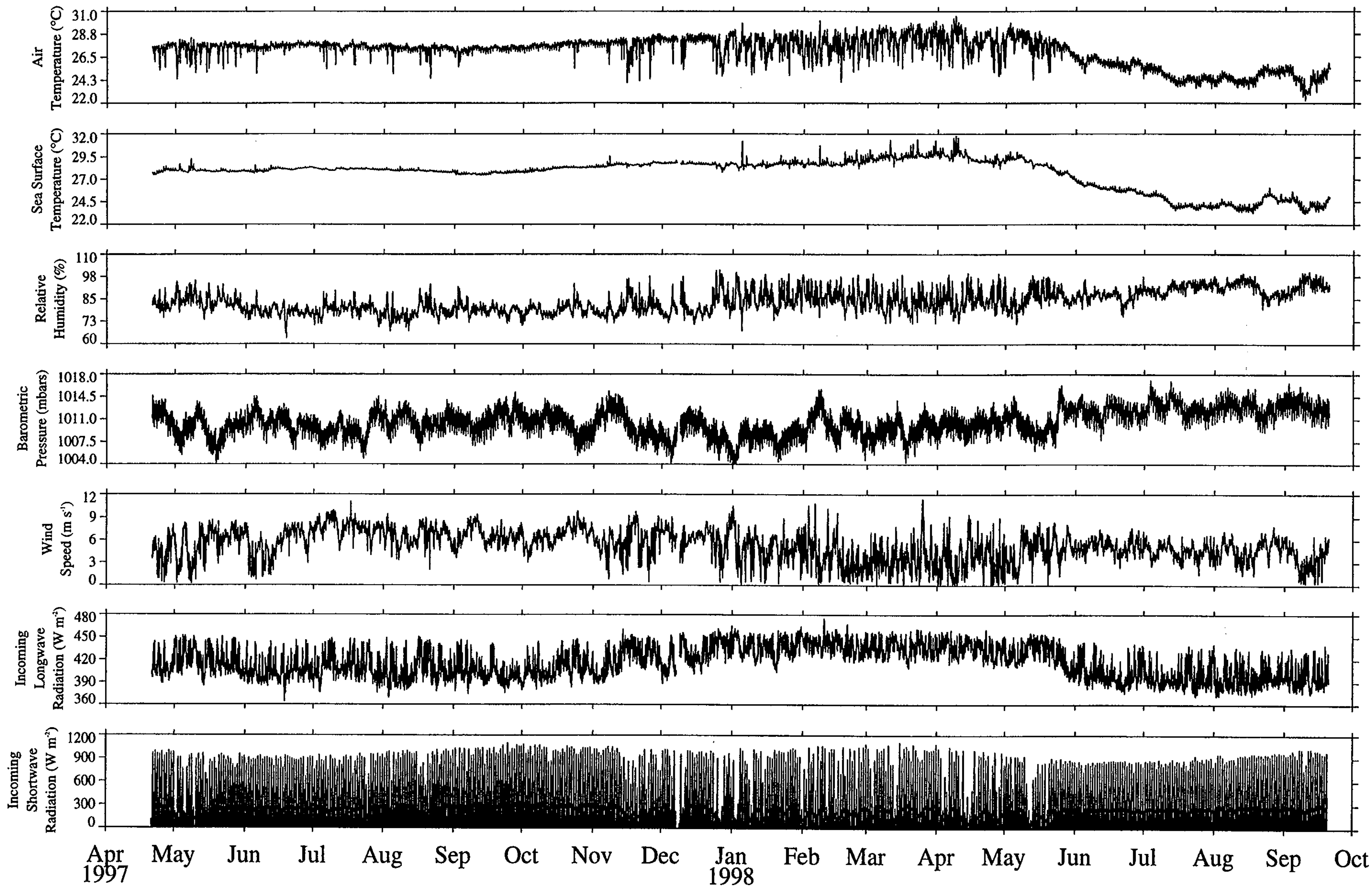


Figure 5-1. Hourly time series of meteorological observations. Incoming short-wave radiation has a 48 hour running mean superimposed on the hourly time series. (PACS South)

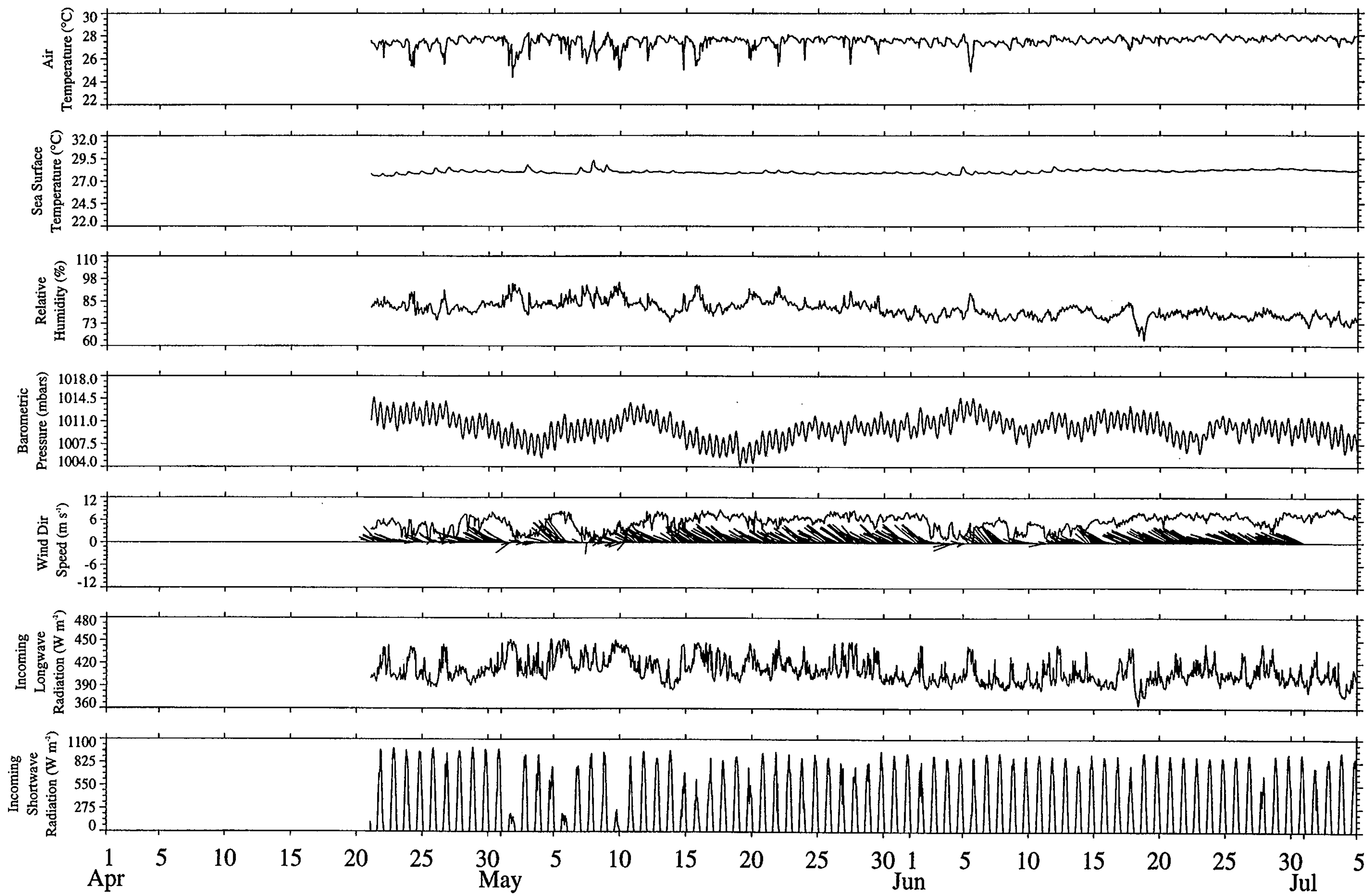


Figure 5-2. Hourly time series of meteorological observations for April through June 1997.
(PACS South)

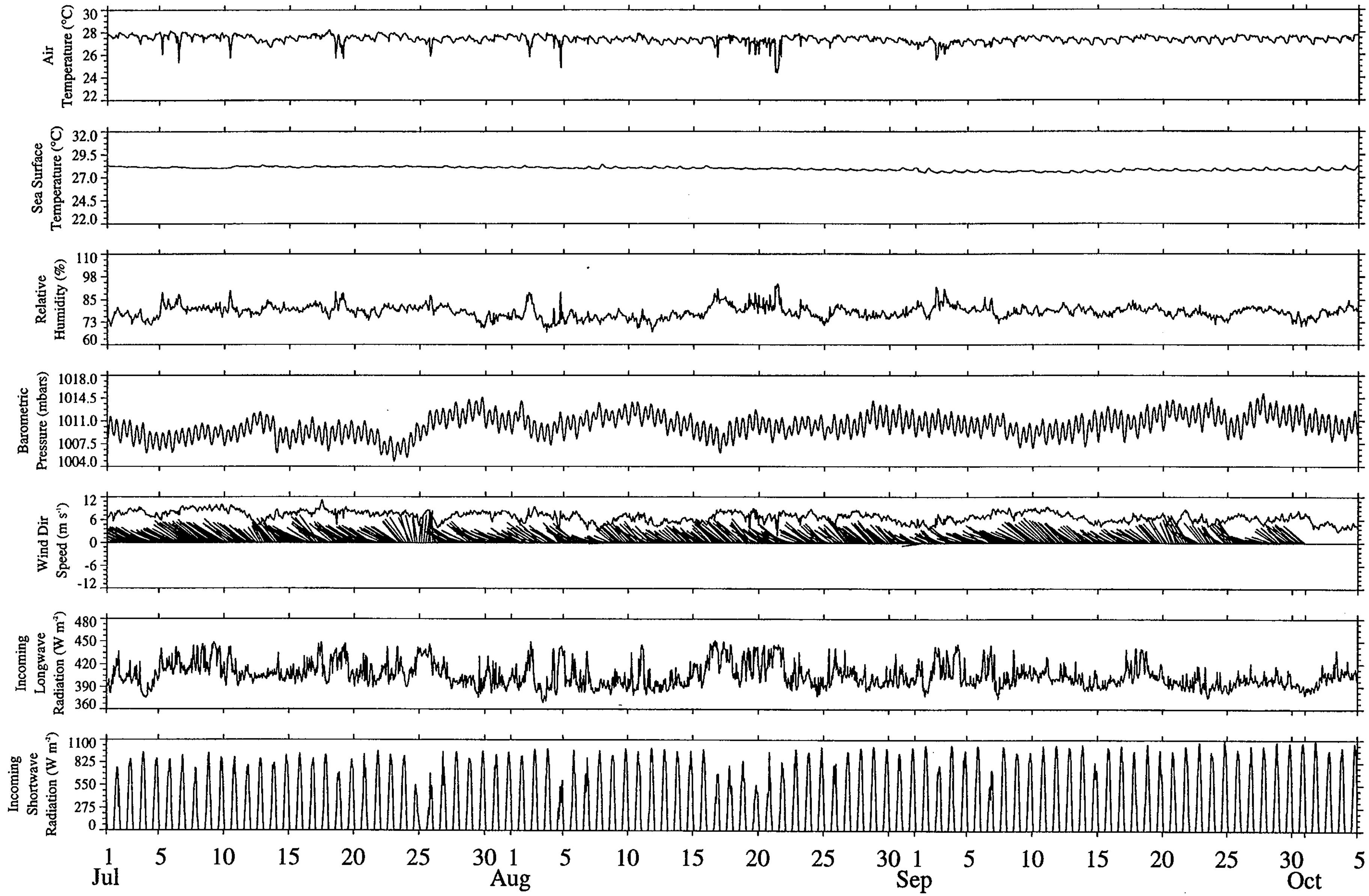


Figure 5-3. Hourly time series of meteorological observations for July through September 1997.
(PACS South)

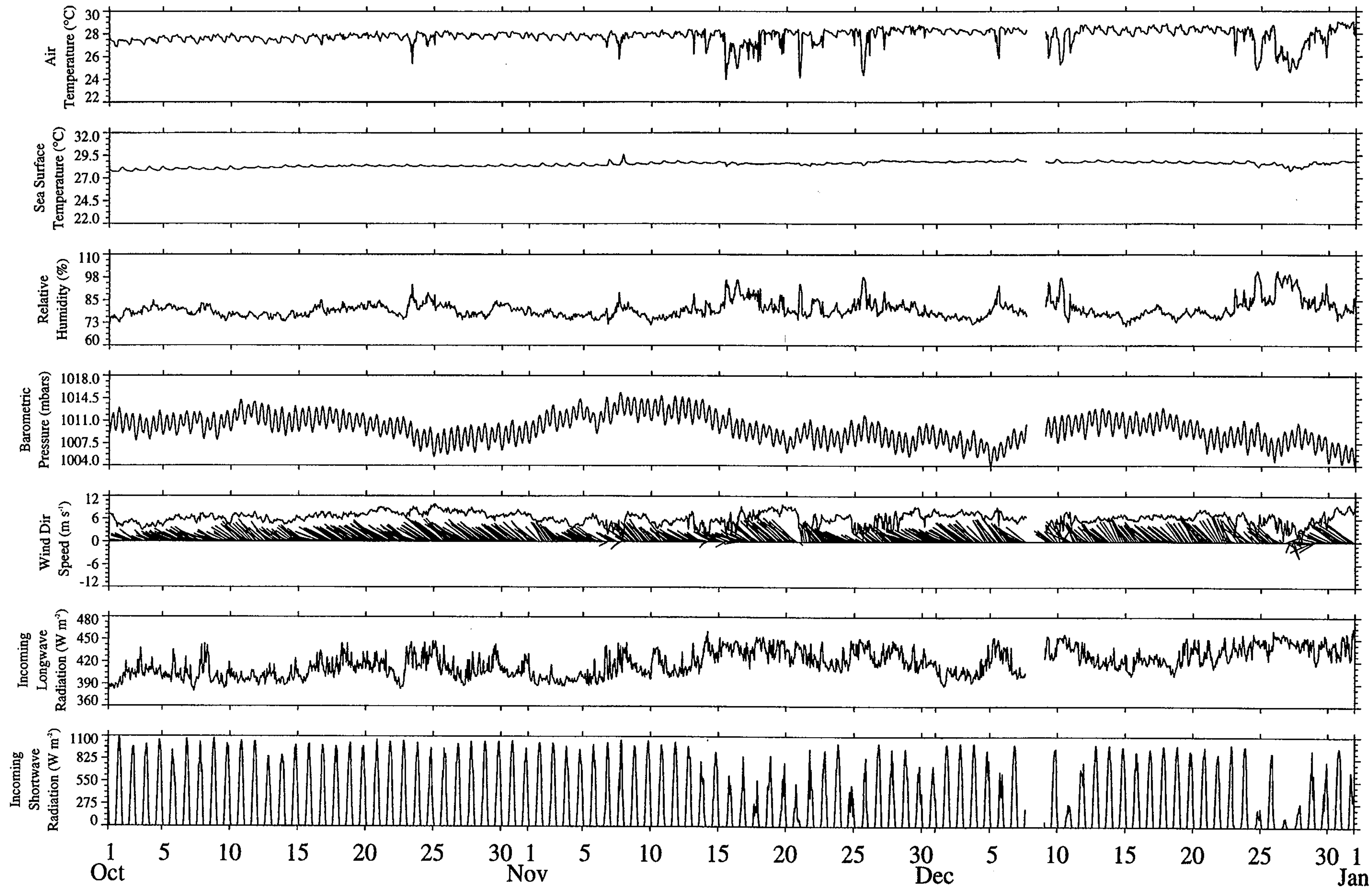


Figure 5-4. Hourly time series of meteorological observations for October through December 1997.
(PACS South)

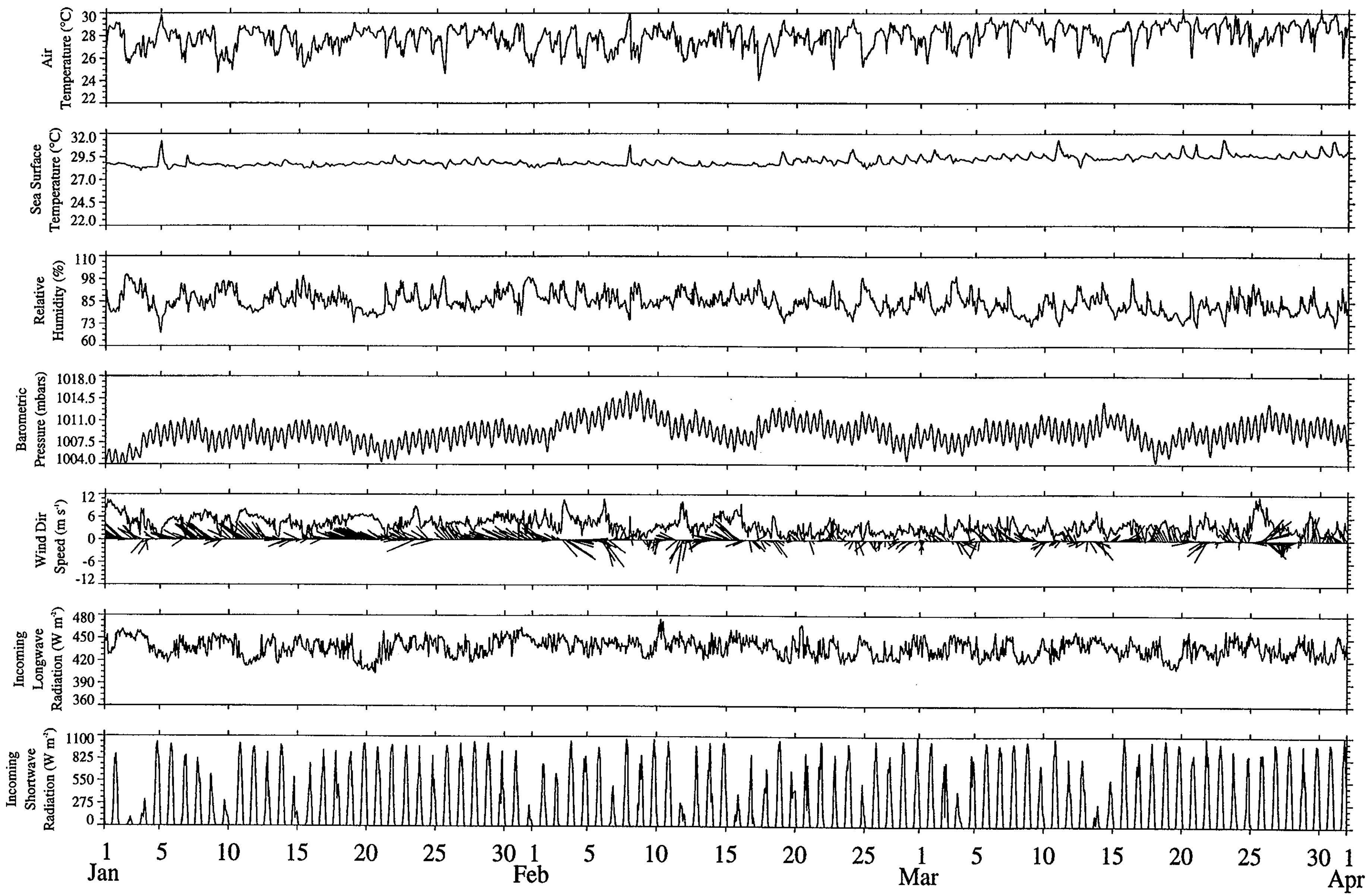


Figure 5-5. Hourly time series of meteorological observations for January through March 1998. (PACS South)

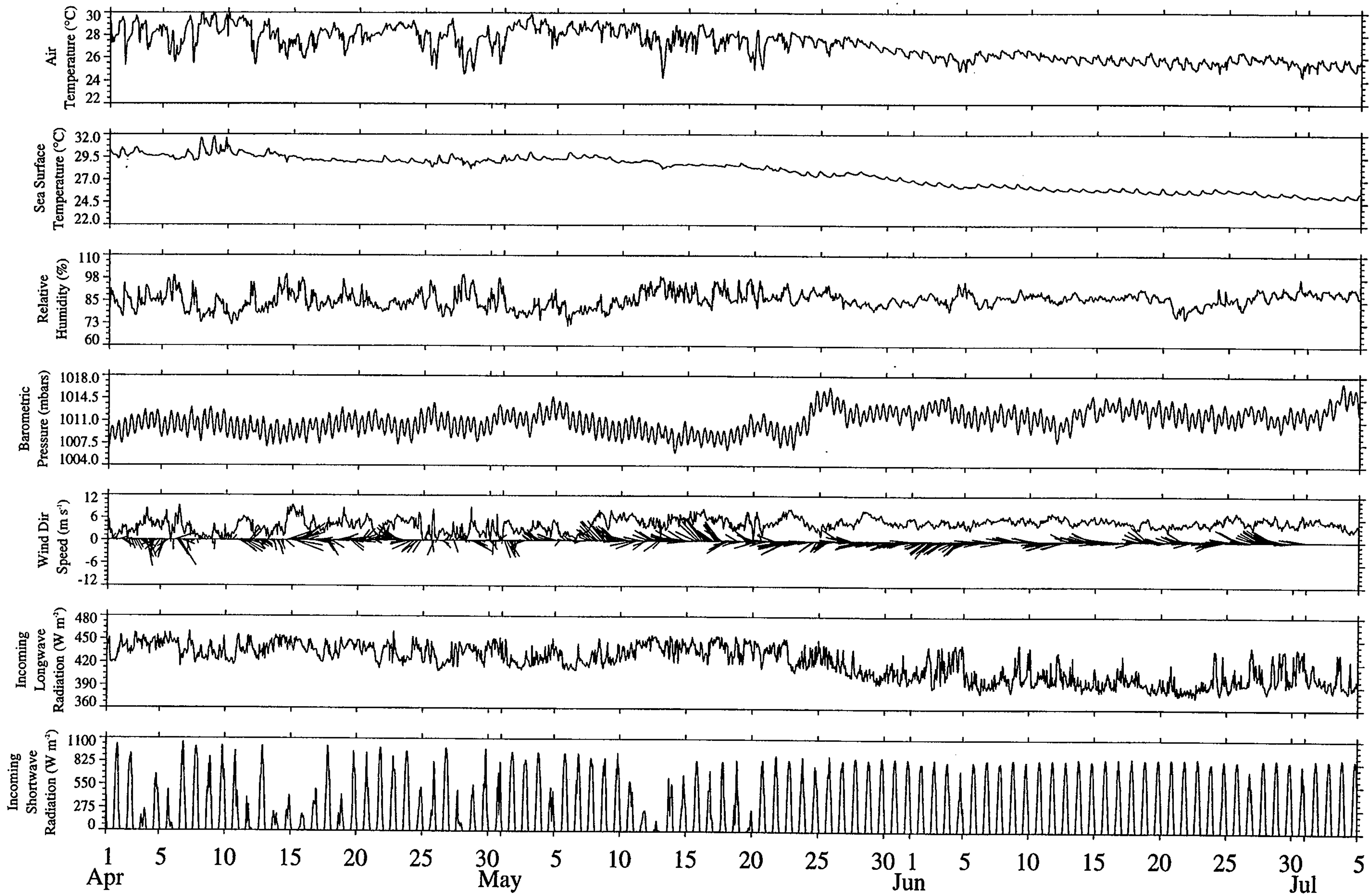


Figure 5-6. Hourly time series of meteorological observations for April through June 1998.
(PACS South)

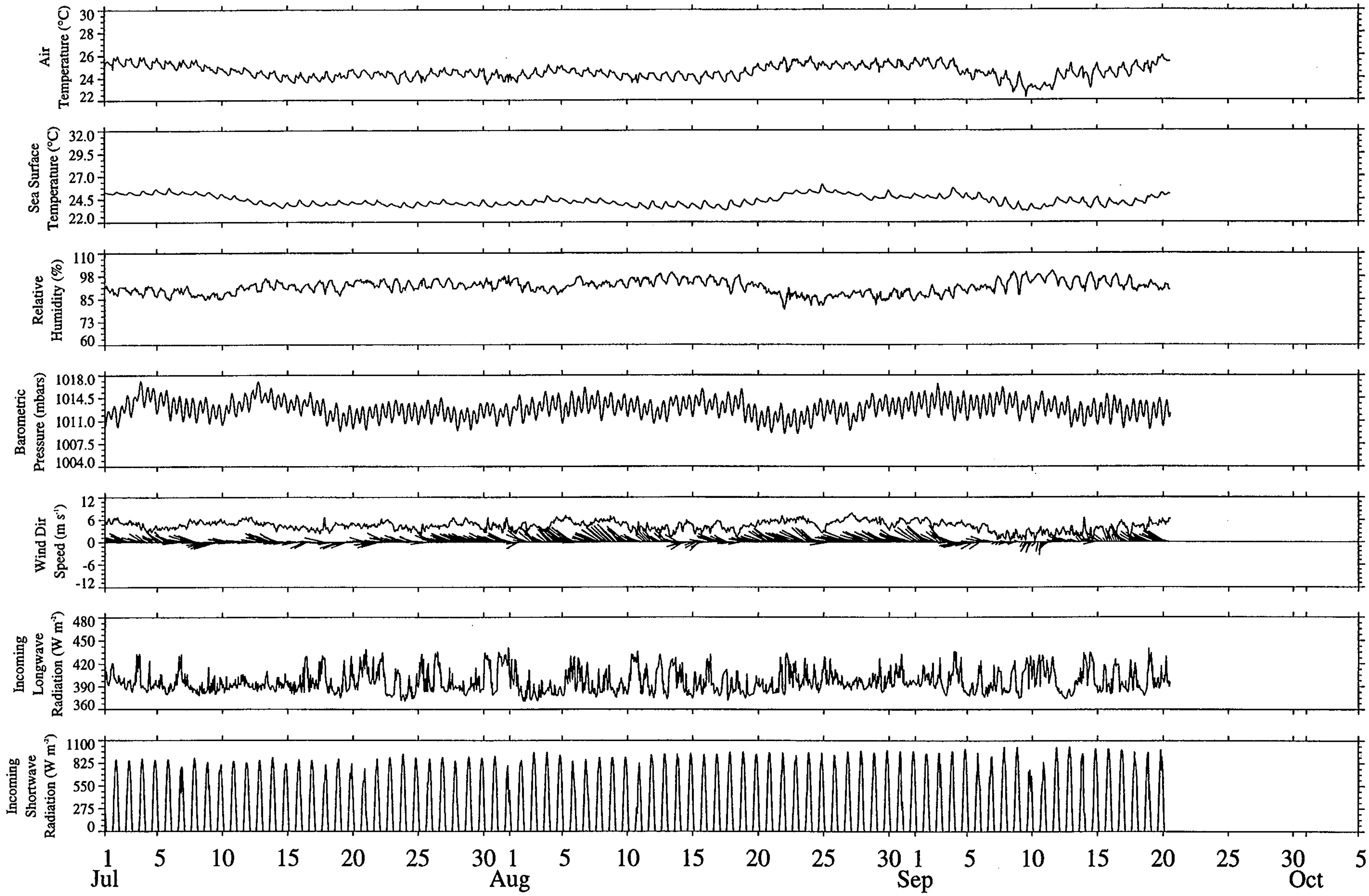


Figure 5-7. Hourly time series of meteorological observations for July through September 1998.
(PACS South)

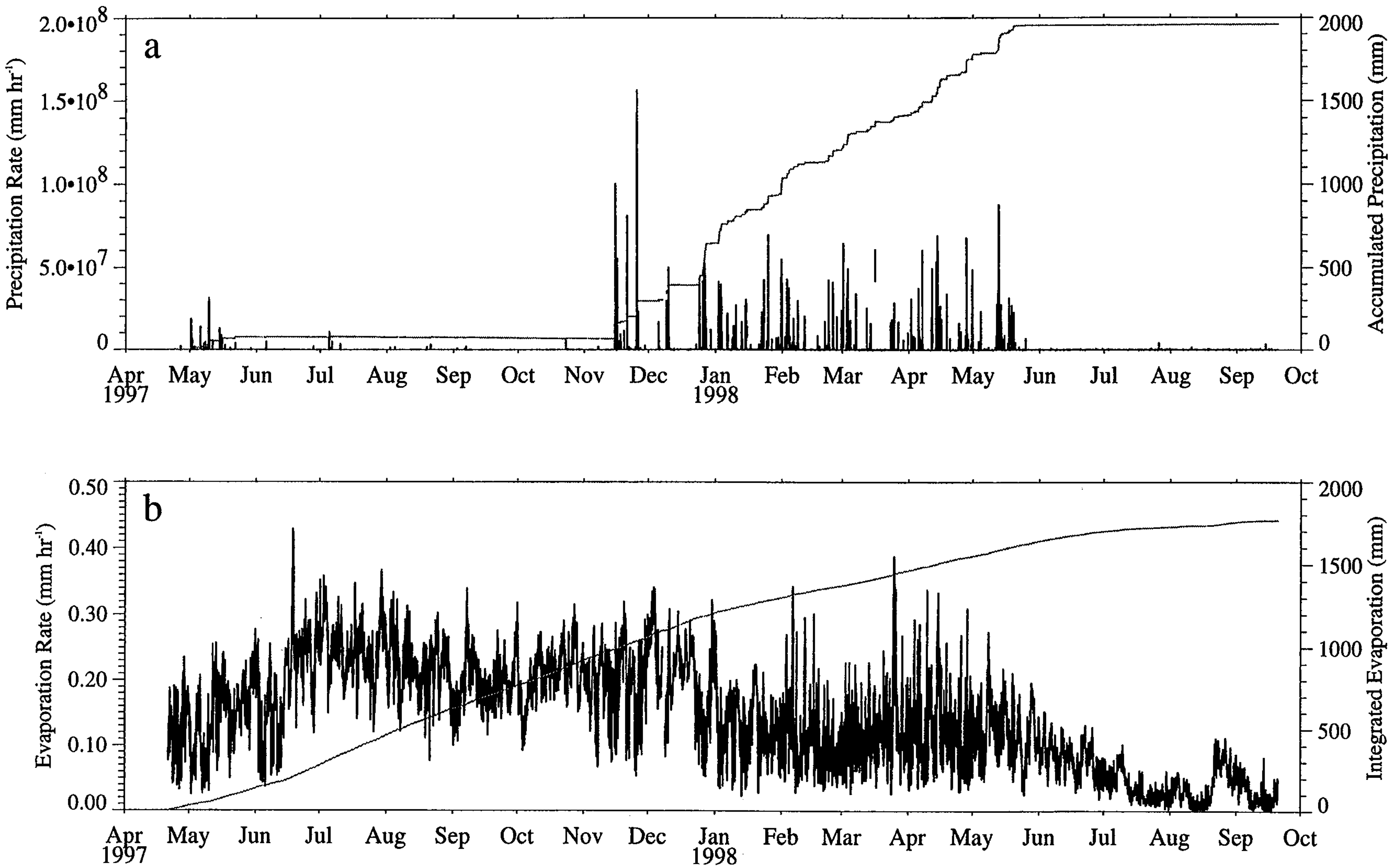


Figure 5-8. (a) Hourly averaged precipitation rate (black) and accumulated precipitation (gray) from IMET self-siphoning rain gauge. (b) Hourly averaged evaporation rate (black) and integrated evaporation (gray) from bulk formulae. (PACS South)

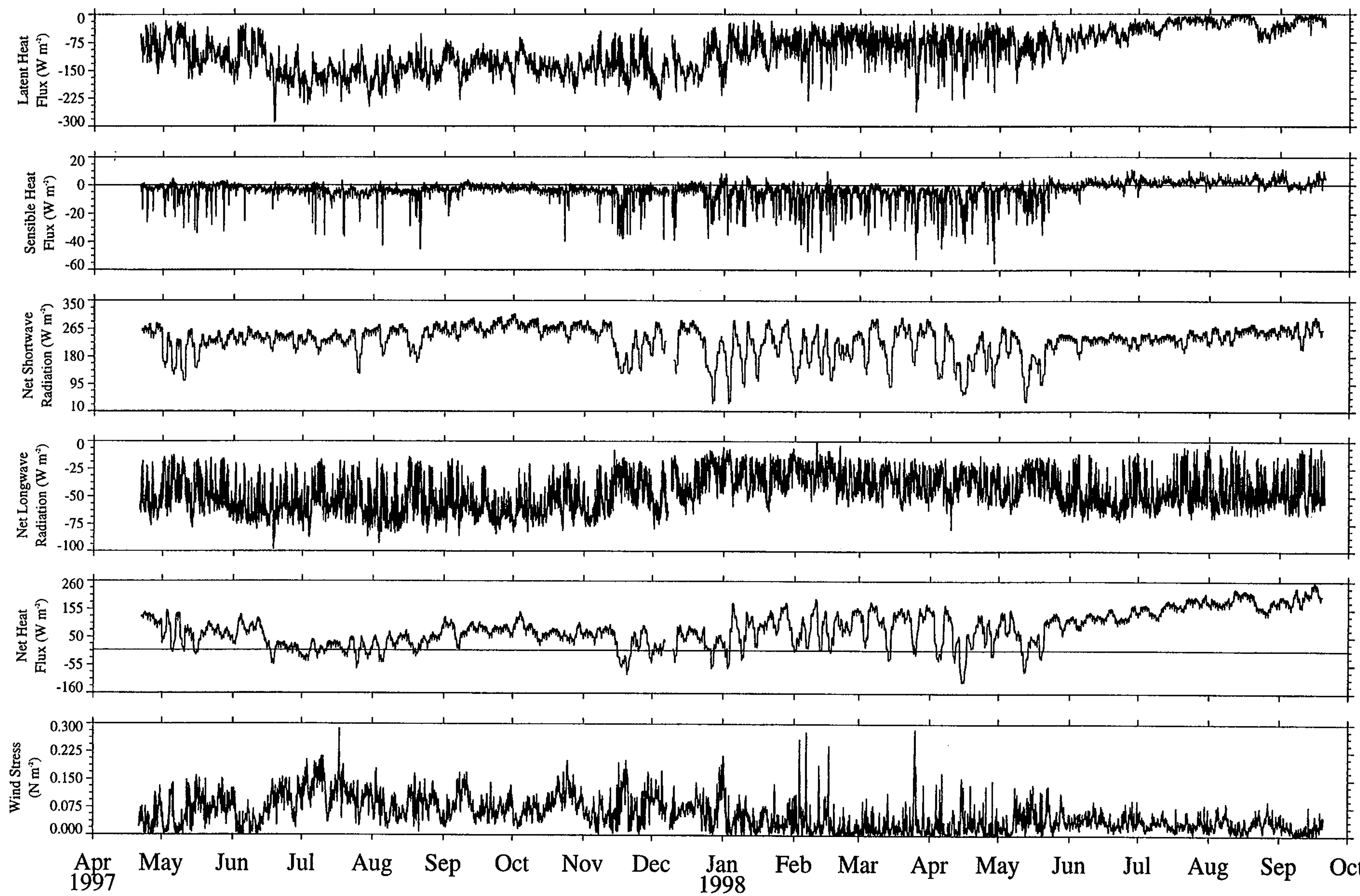


Figure 5-9. Hourly time series of estimated heat and momentum fluxes. Net short-wave and net heat flux each have a 48 hour running mean applied. (PACS South)

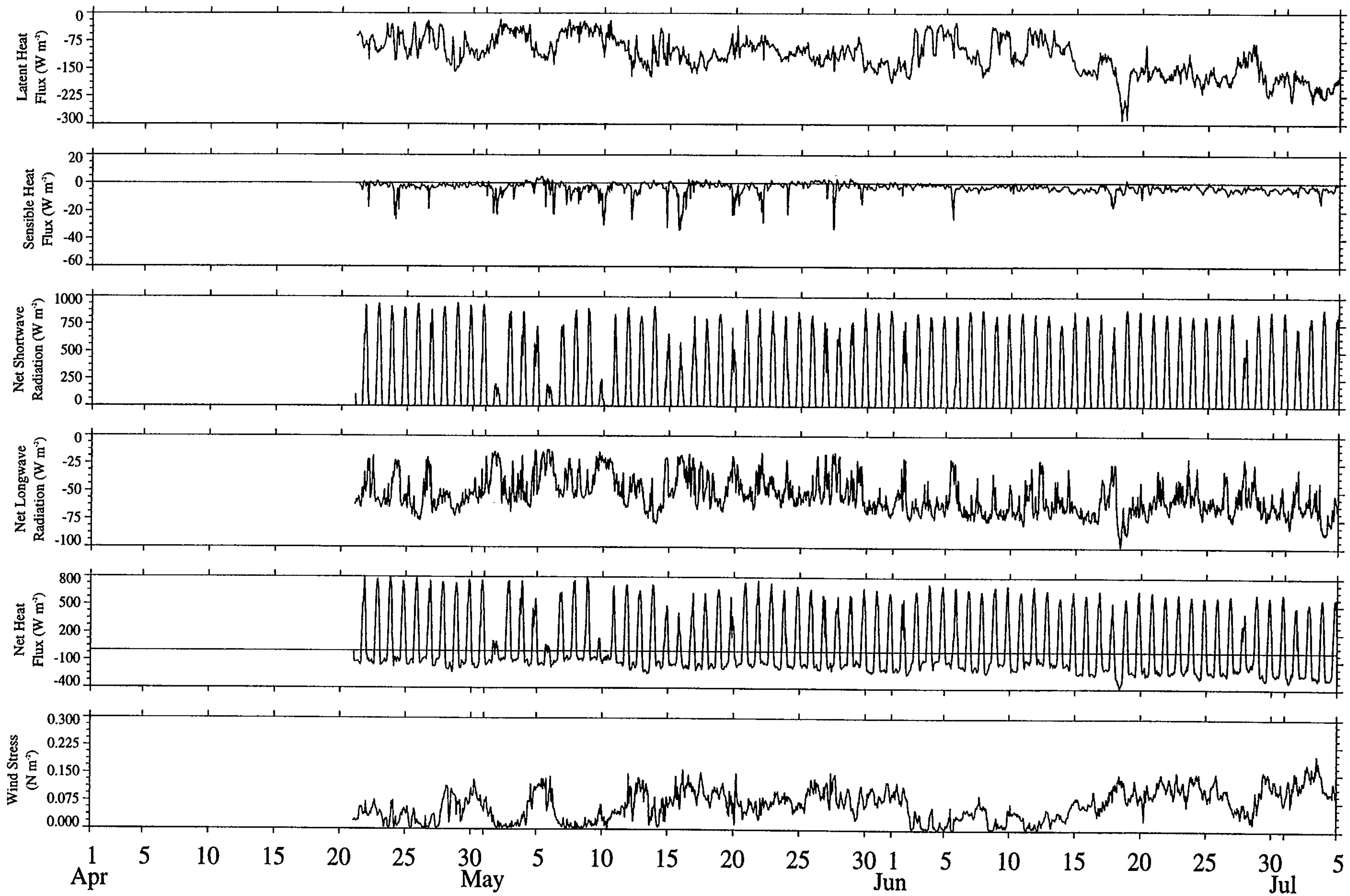


Figure 5-10. Hourly time series of estimated heat and momentum fluxes for April through June 1997.
(PACS South)

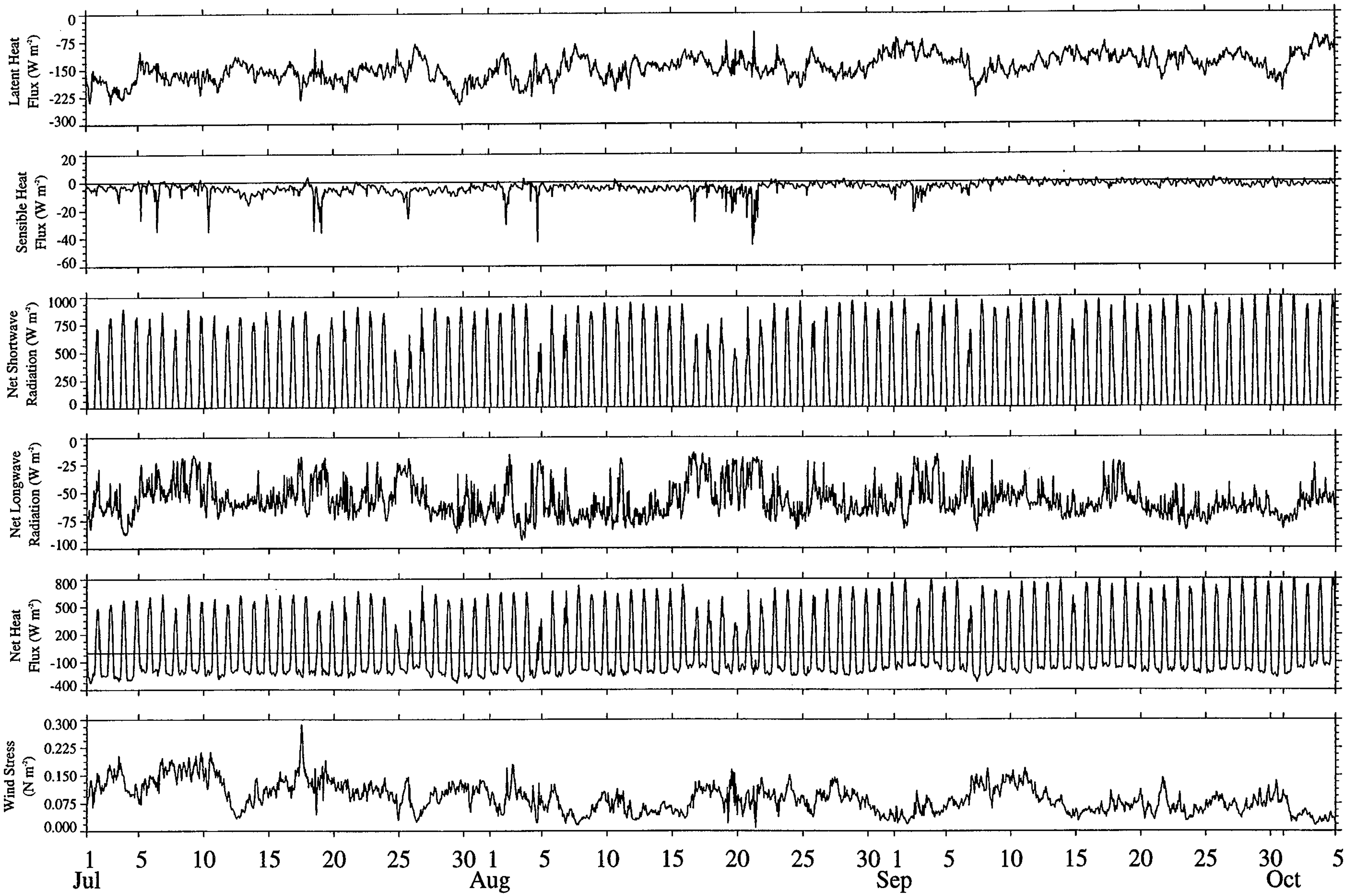


Figure 5-11. Hourly time series of estimated heat and momentum fluxes for July through September 1997. (PACS South)

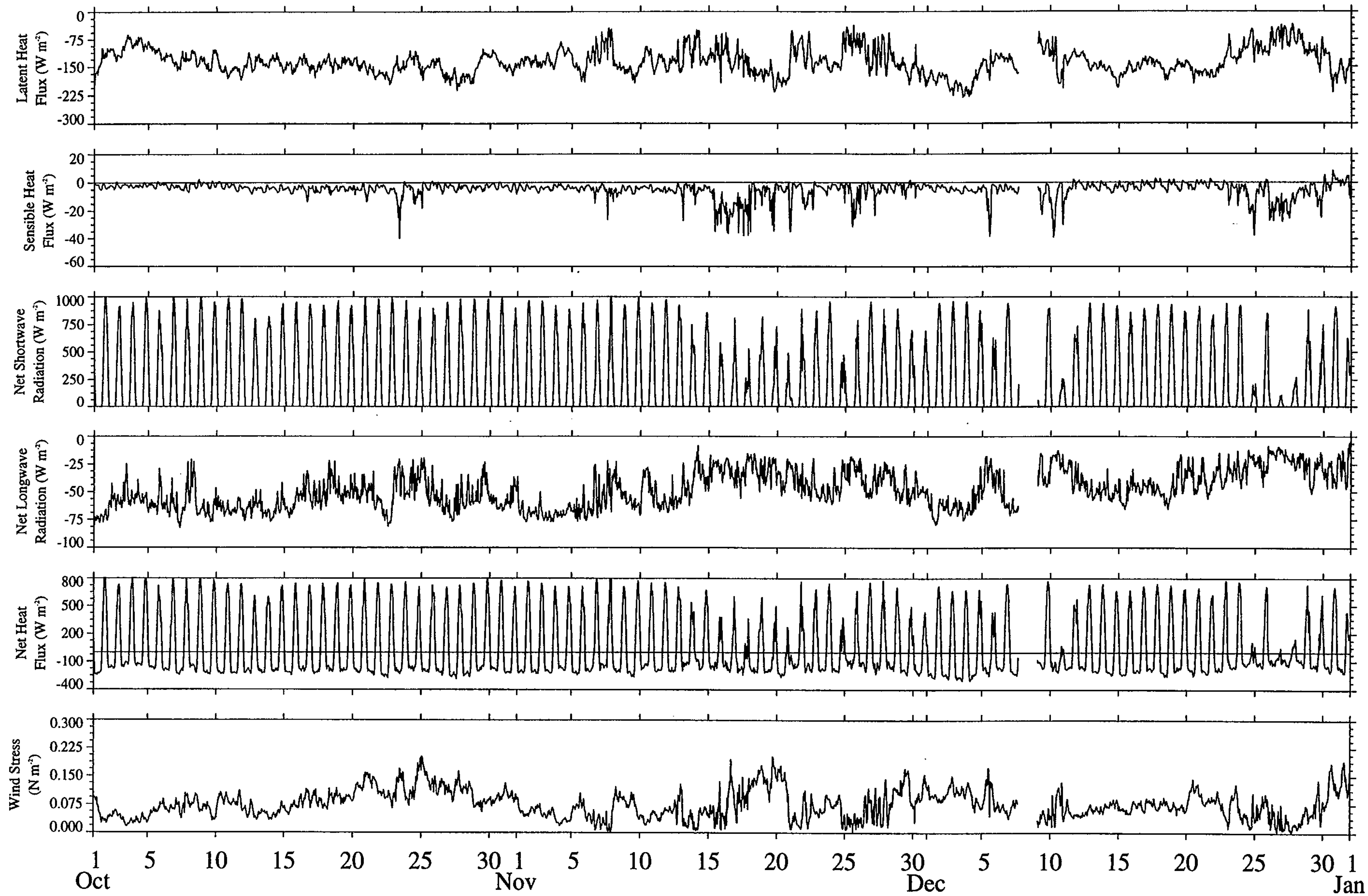


Figure 5-12. Hourly time series of estimated heat and momentum fluxes for October through December 1997.
(PACS South)

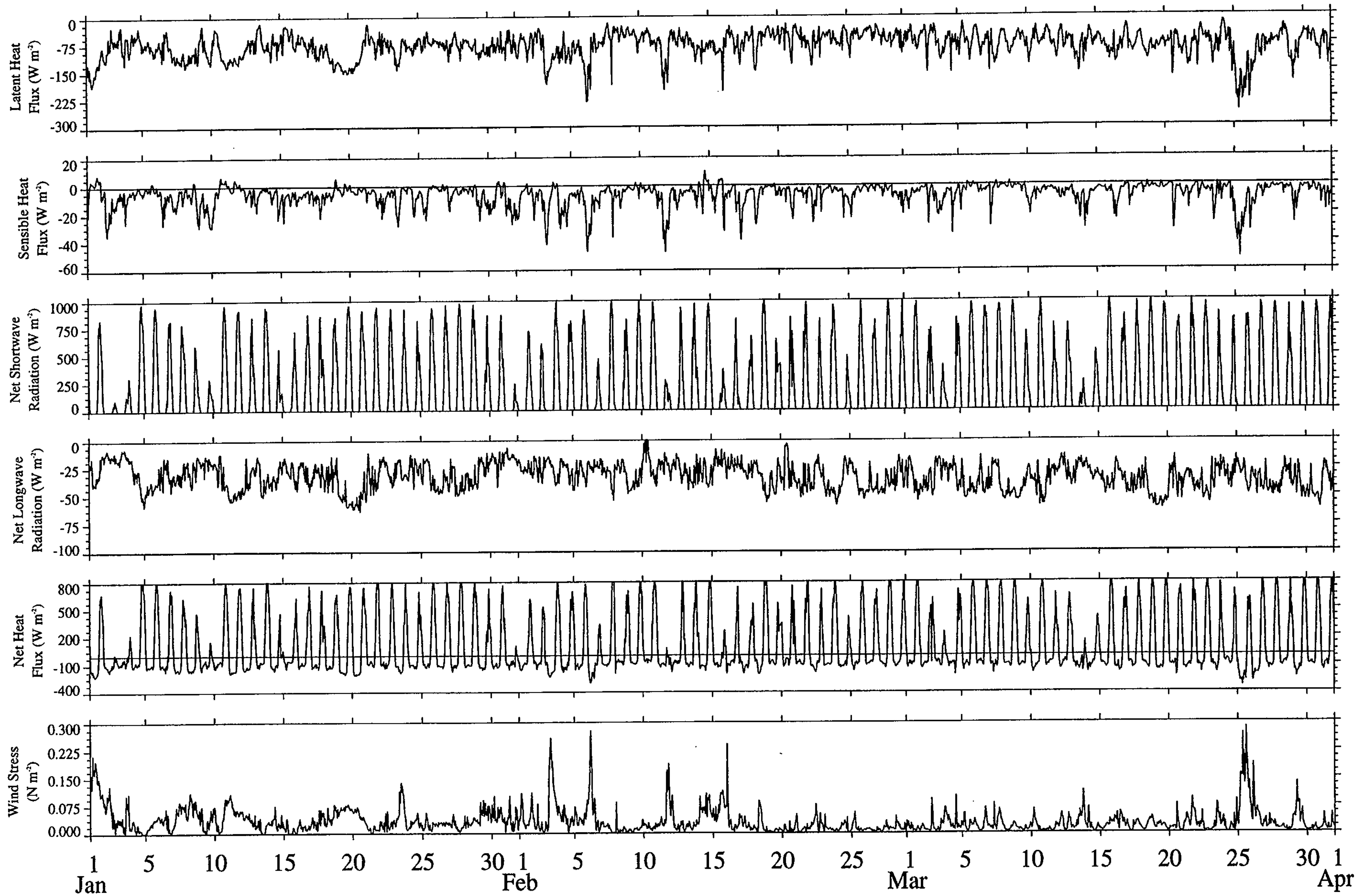


Figure 5-13. Hourly time series of estimated heat and momentum fluxes for January through March 1998. (PACS South)

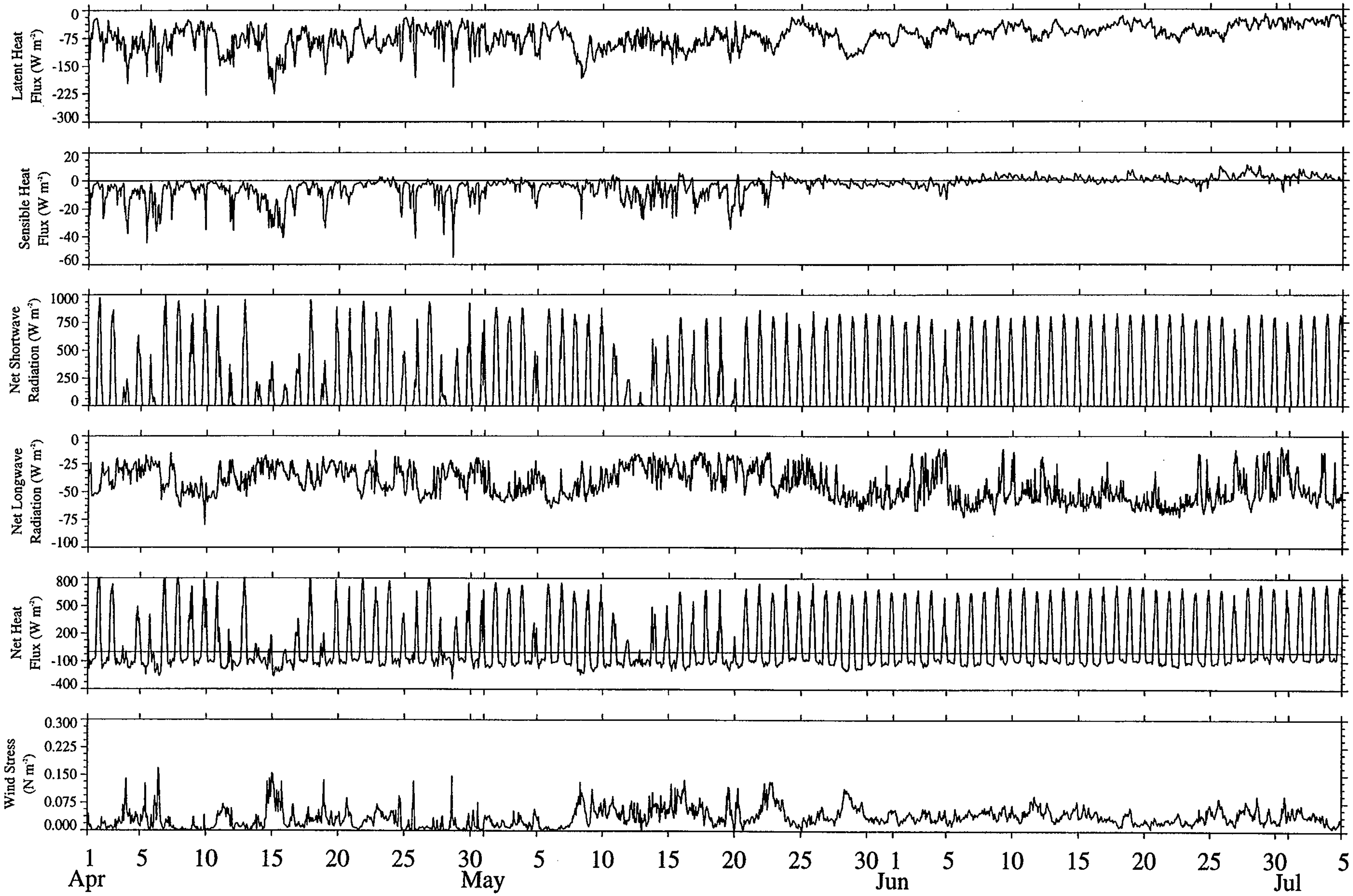


Figure 5-14. Hourly time series of estimated heat and momentum fluxes for April through June 1998. (PACS South)

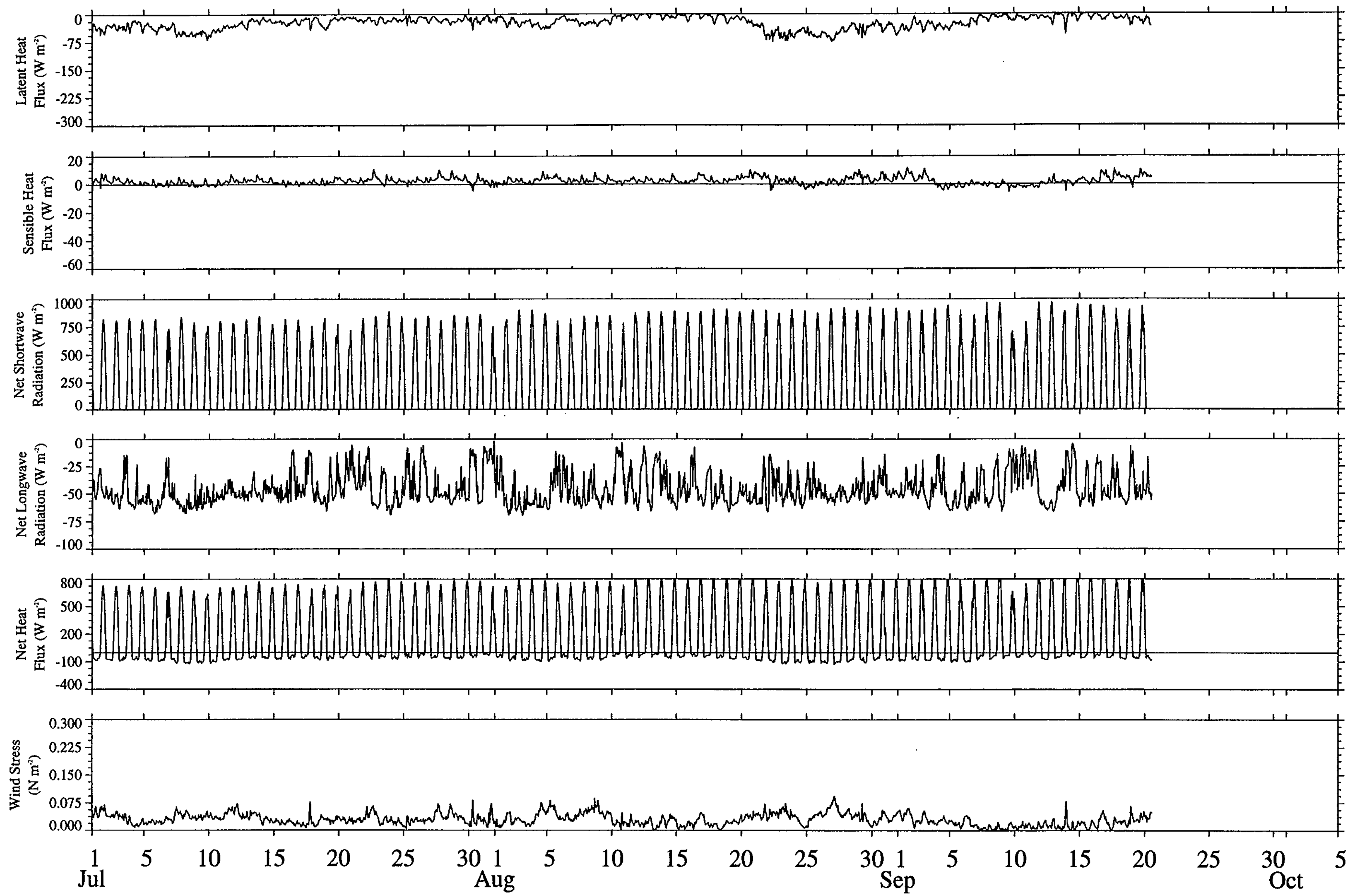


Figure 5-15. Hourly time series of estimated heat and momentum fluxes for July through September 1998. (PACS South)

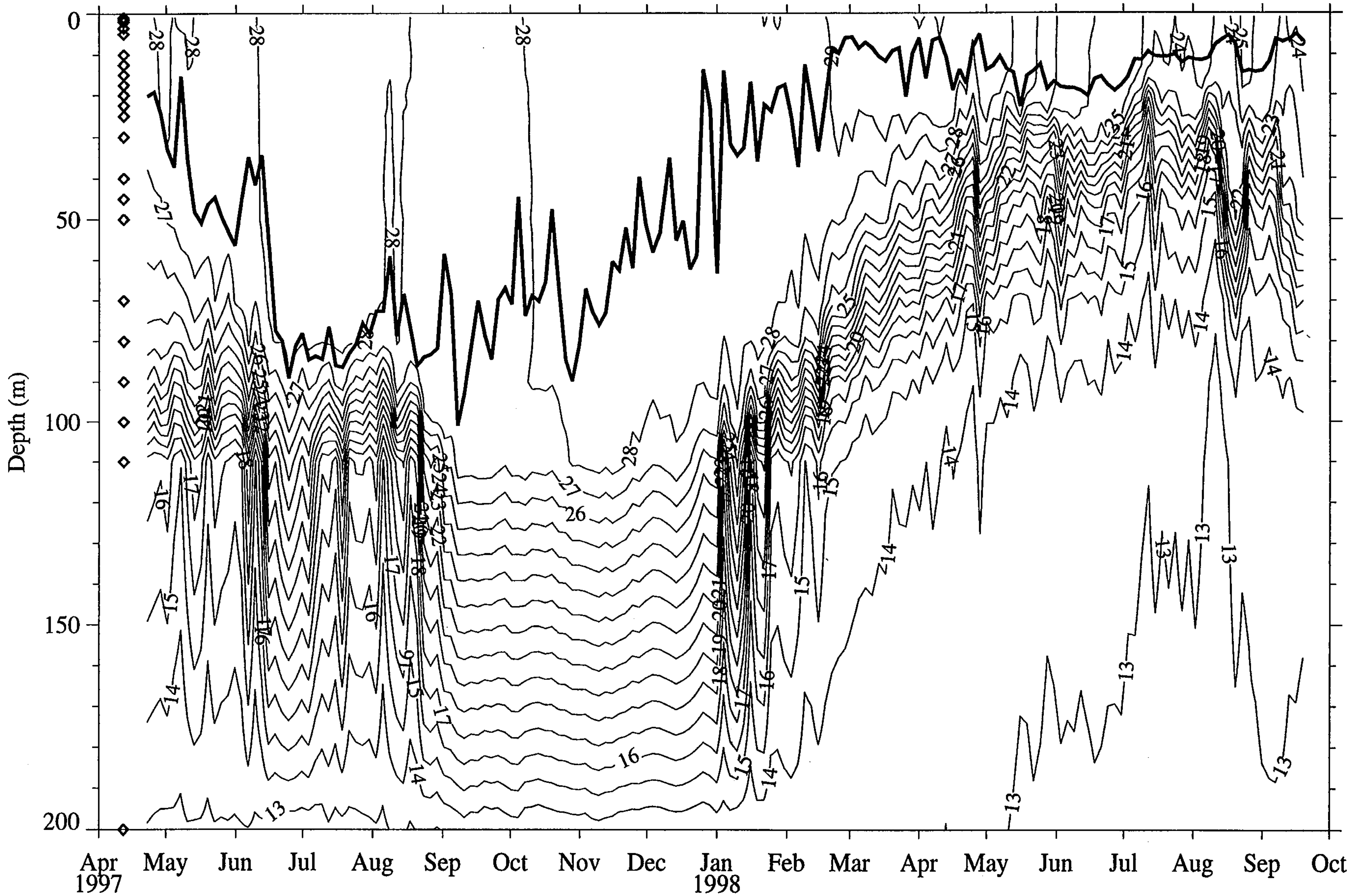


Figure 5-16. Contour plot of 36 hour averaged temperature and mixed layer depth (thick). Diamonds indicate measurement depths. Isotherms are in units of °C.

(PACS South)

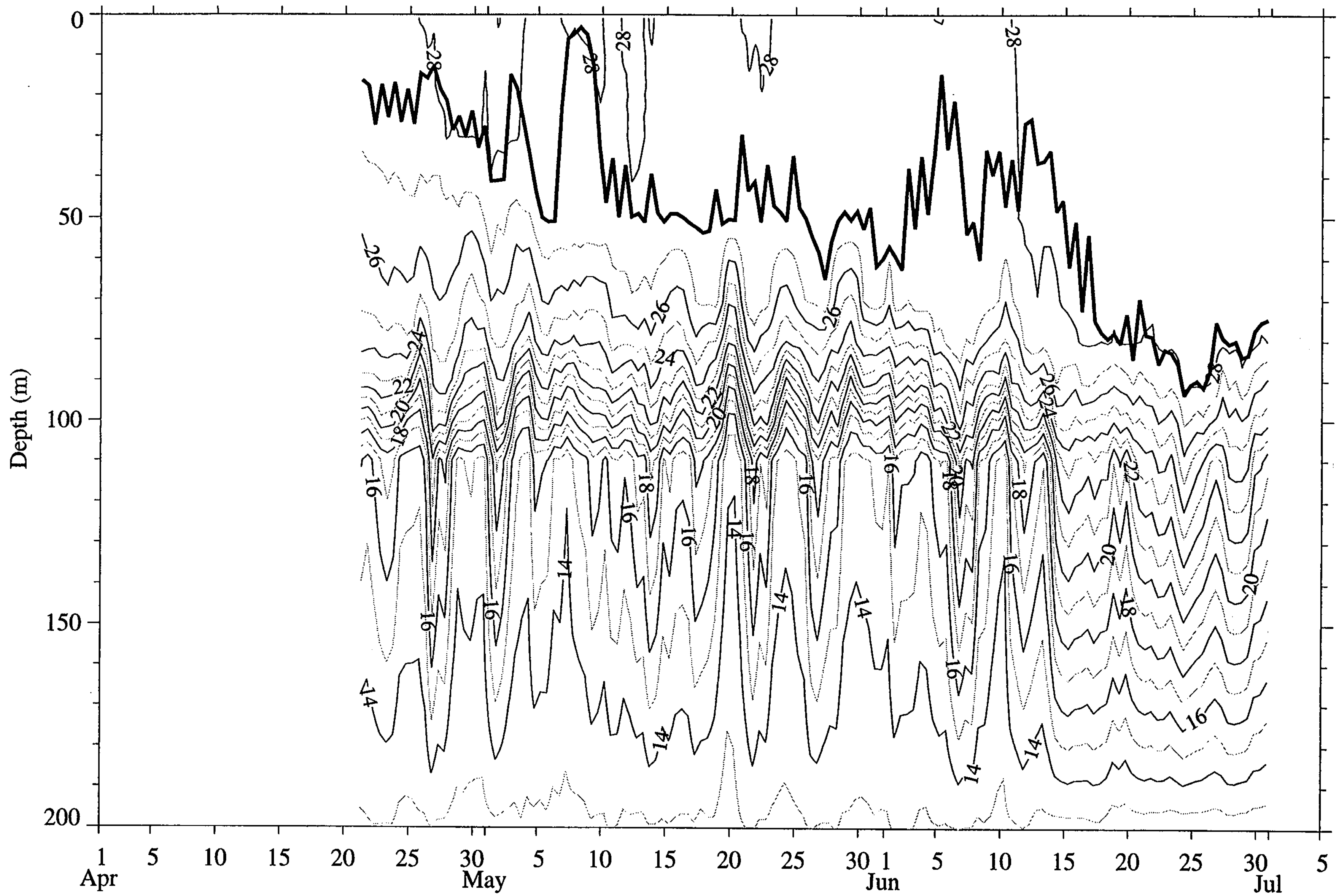


Figure 5-17. Contour plot of hourly averaged temperature and mixed layer depth (thick) for April through June 1997. Isotherms are in units of °C. (PACS South)

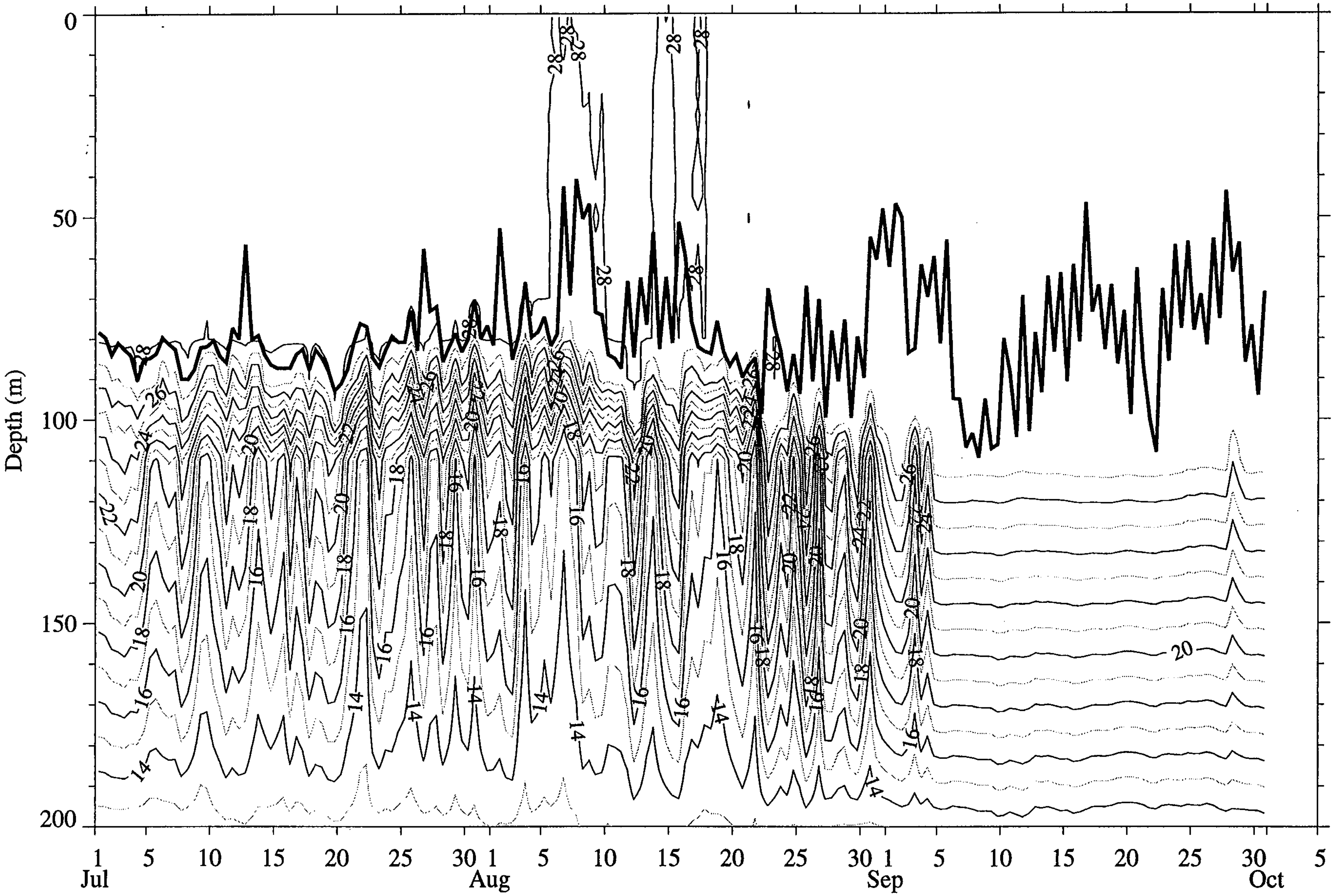


Figure 5-18. Contour plot of hourly averaged temperature and mixed layer depth (thick) for July through September 1997. Isotherms are in units of °C. (PACS South)

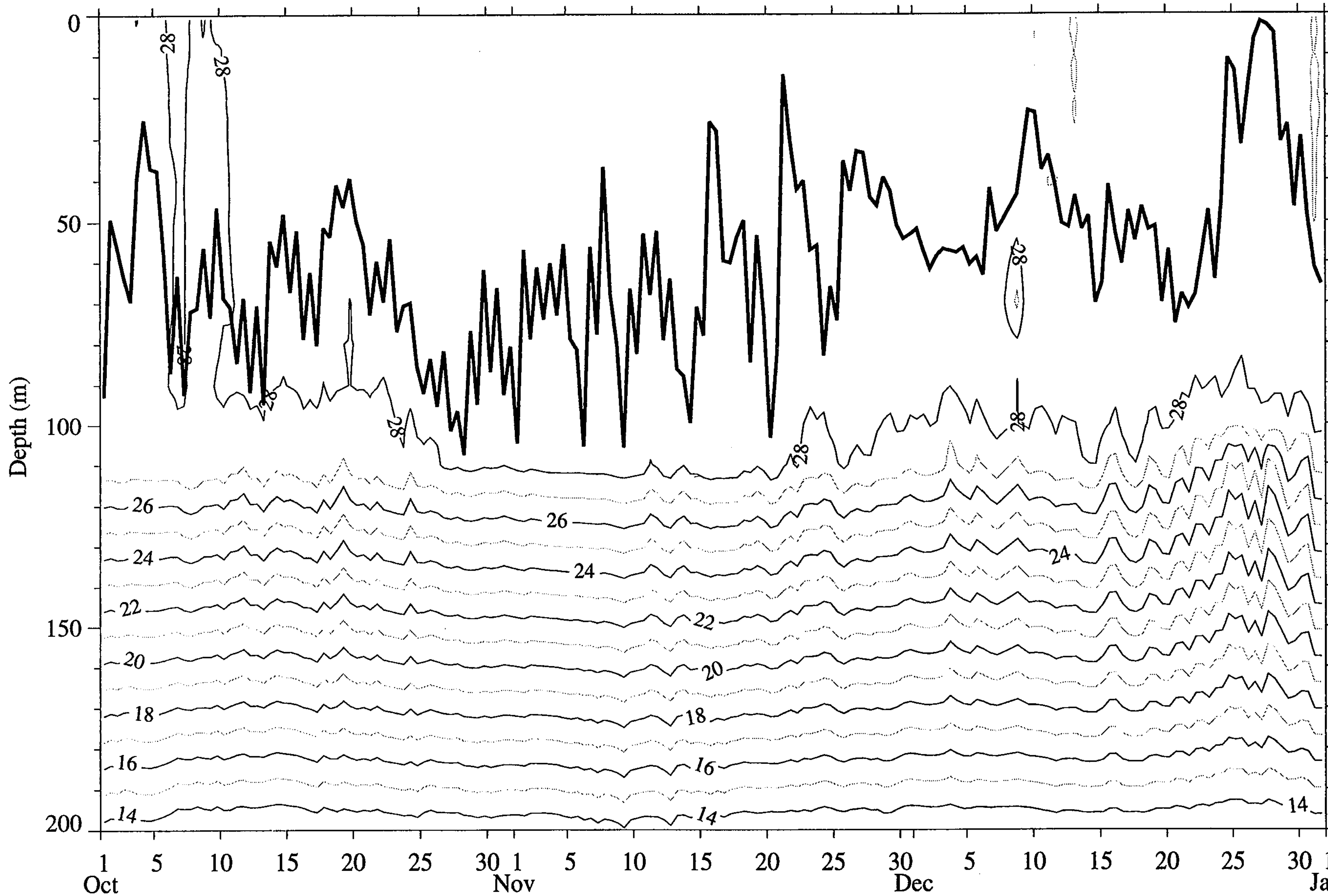


Figure 5-19. Contour plot of hourly averaged temperature and mixed layer depth (thick) for October through December 1997. Isotherms are in units of °C. (PACS South)

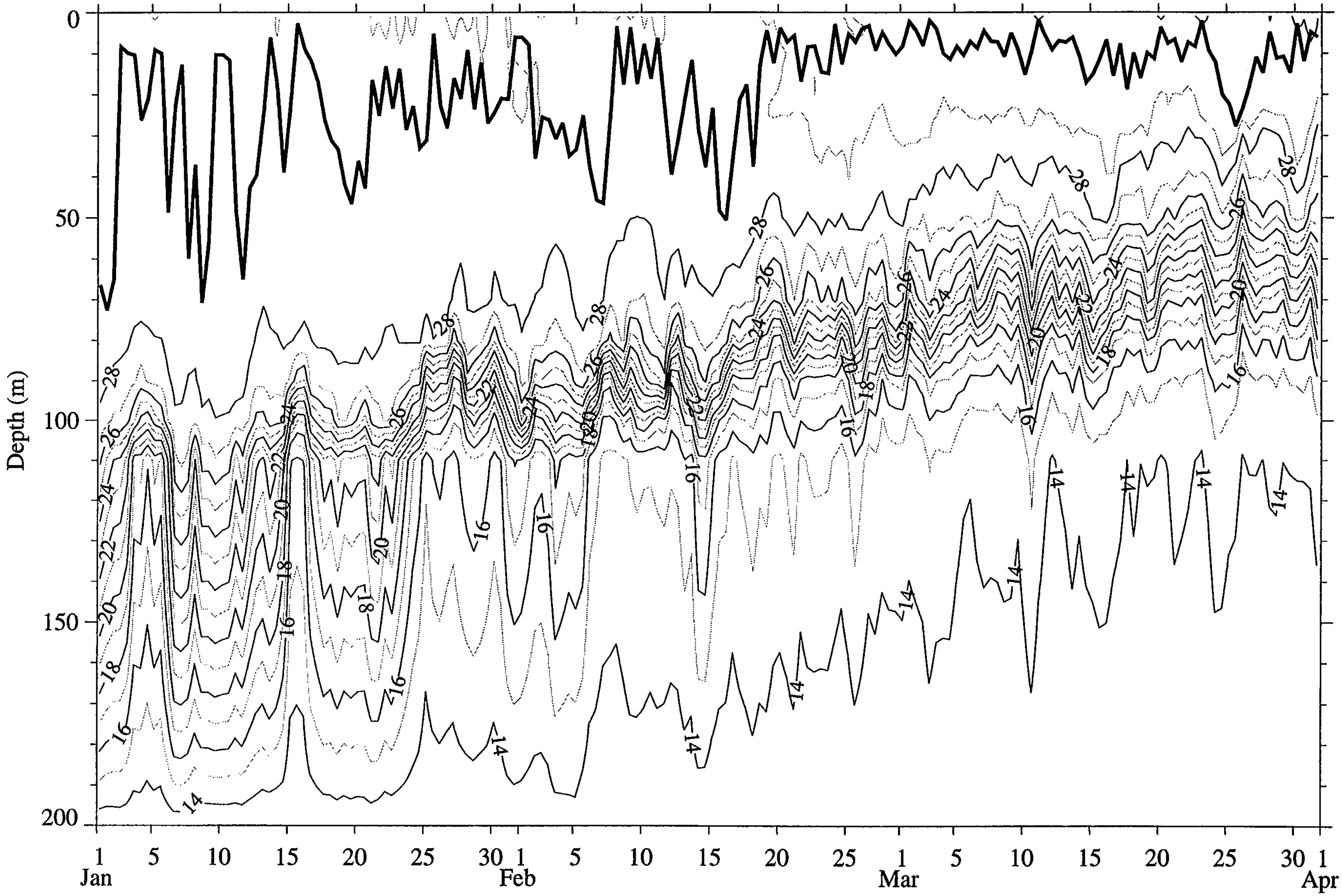


Figure 5-20. Contour plot of hourly averaged temperature and mixed layer depth (thick) for January through March 1998. Isotherms are in units of °C. (PACS South)

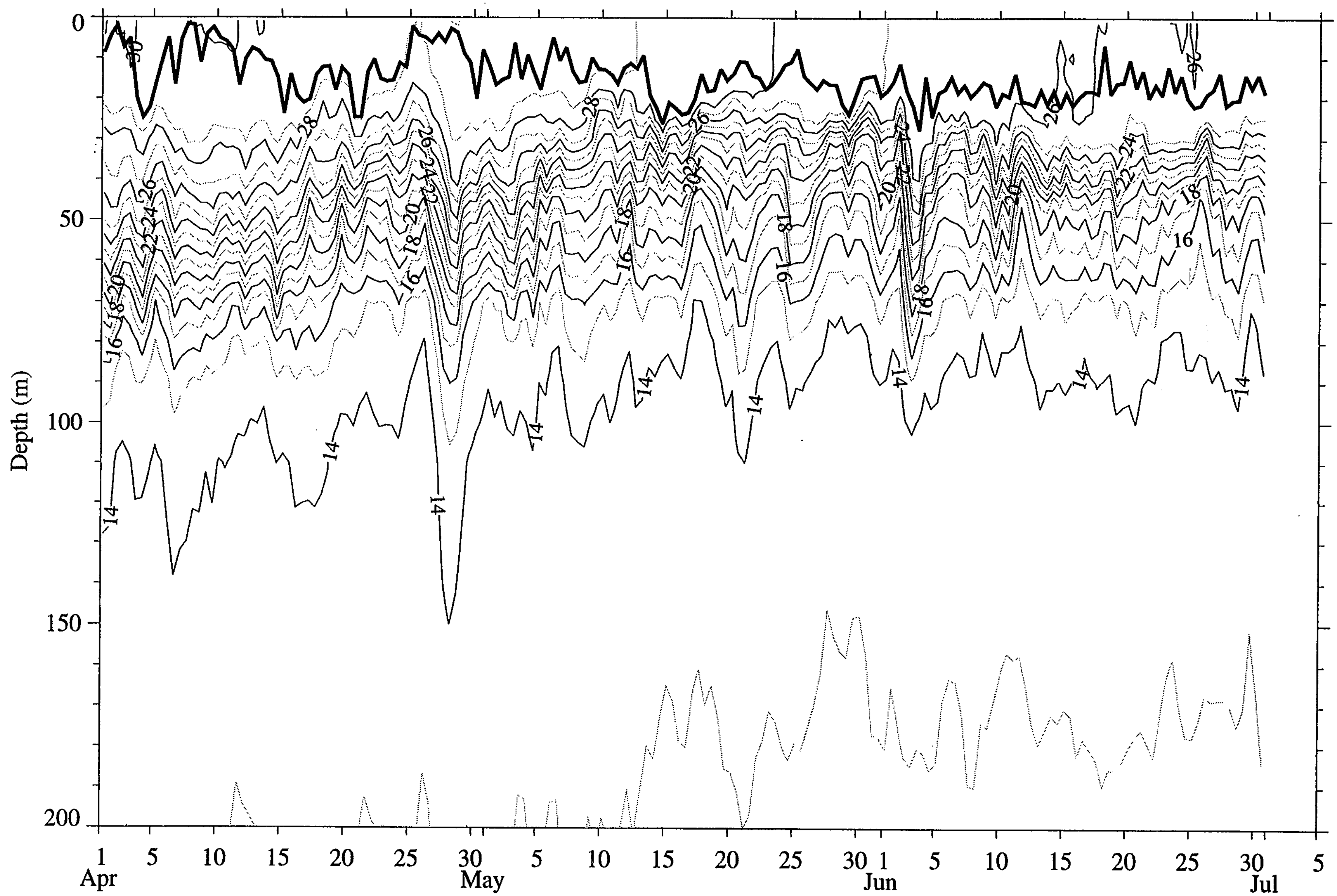


Figure 5-21. Contour plot of hourly averaged temperature and mixed layer depth (thick) for April through June 1998. Isotherms are in units of °C. (PACS South)

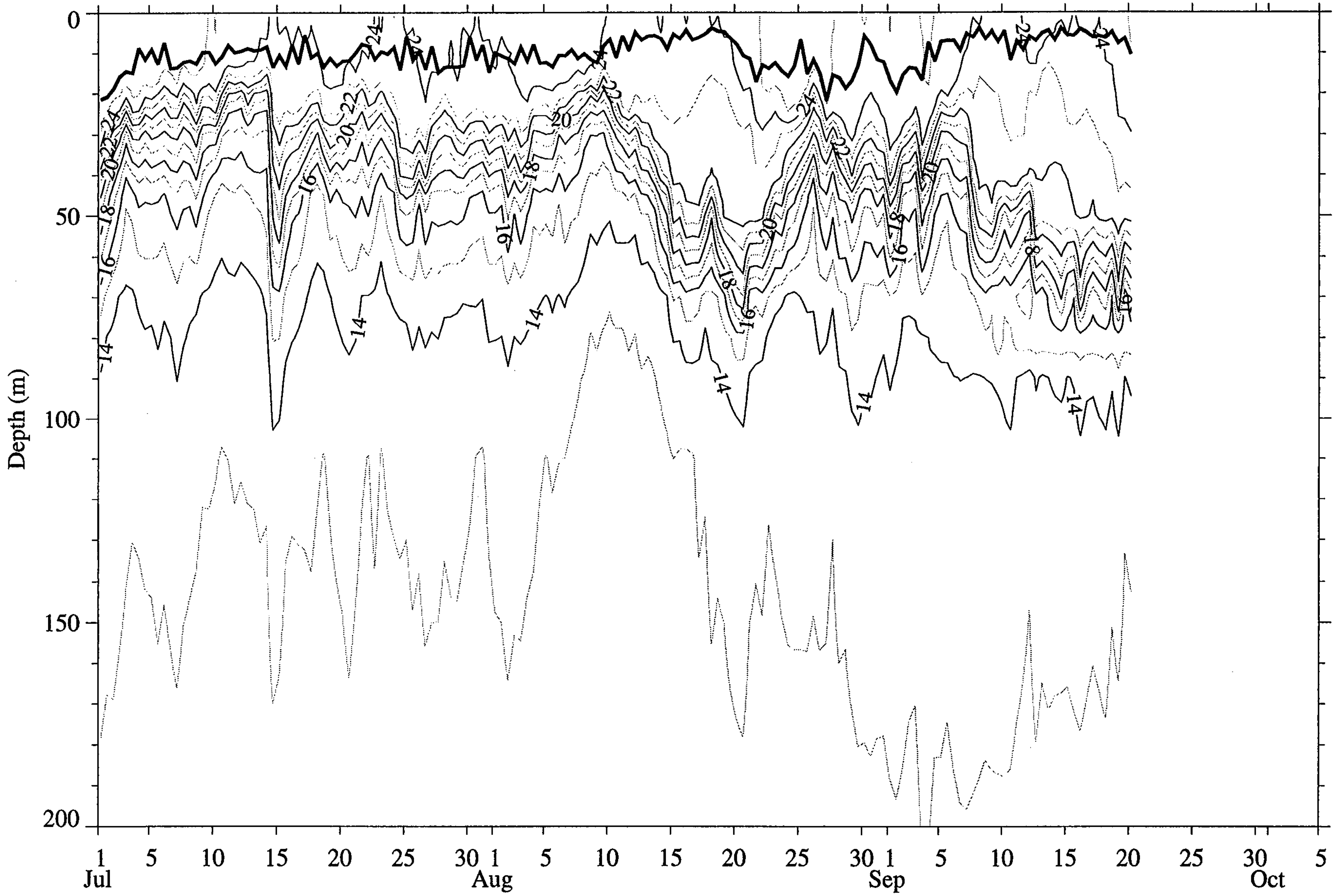


Figure 5-22. Contour plot of hourly averaged temperature and mixed layer depth (thick) for July through September 1998. Isotherms are in units of °C. (PACS South)

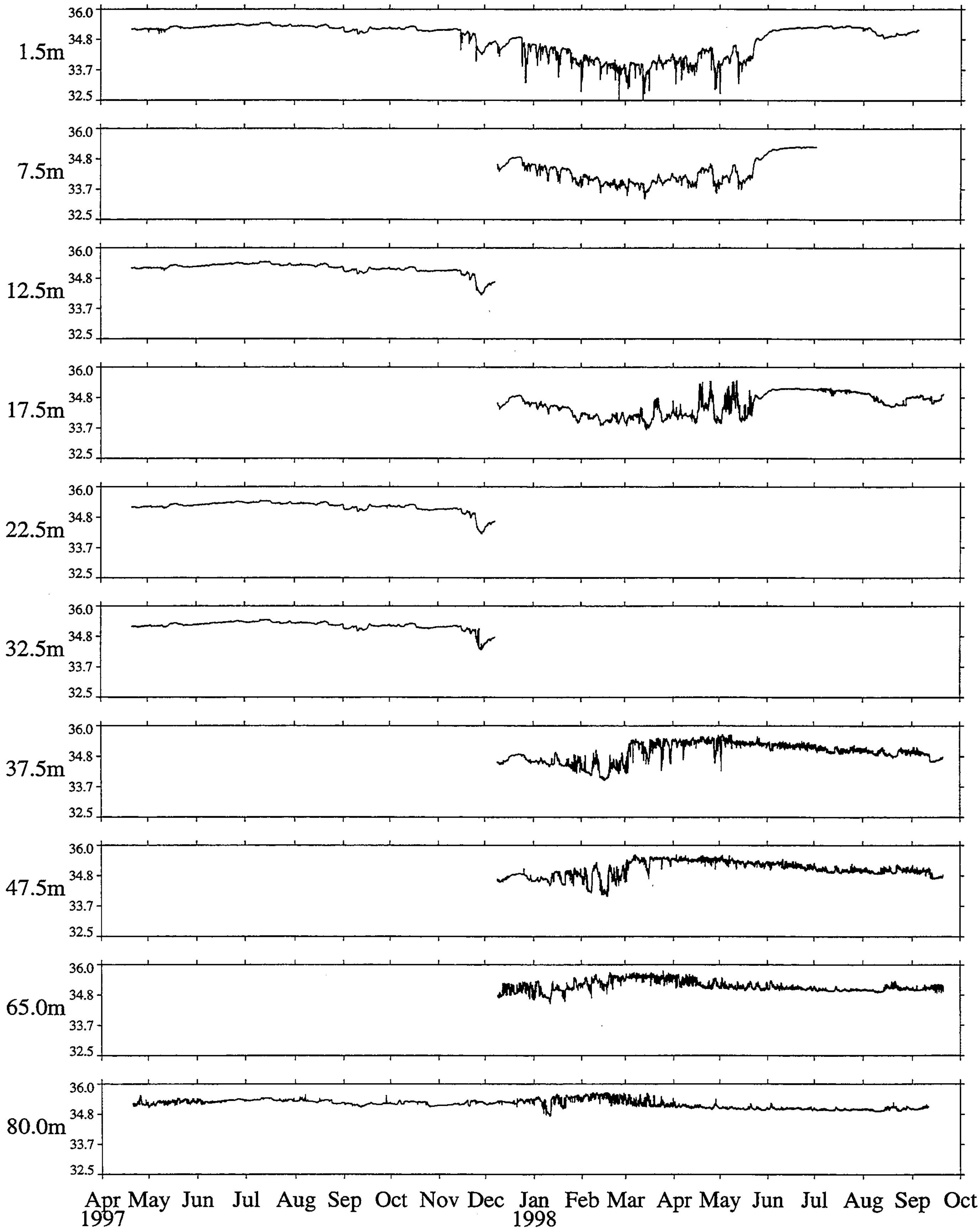


Figure 5-23. One hour salinity in PSU at selected depths.
(PACS South)

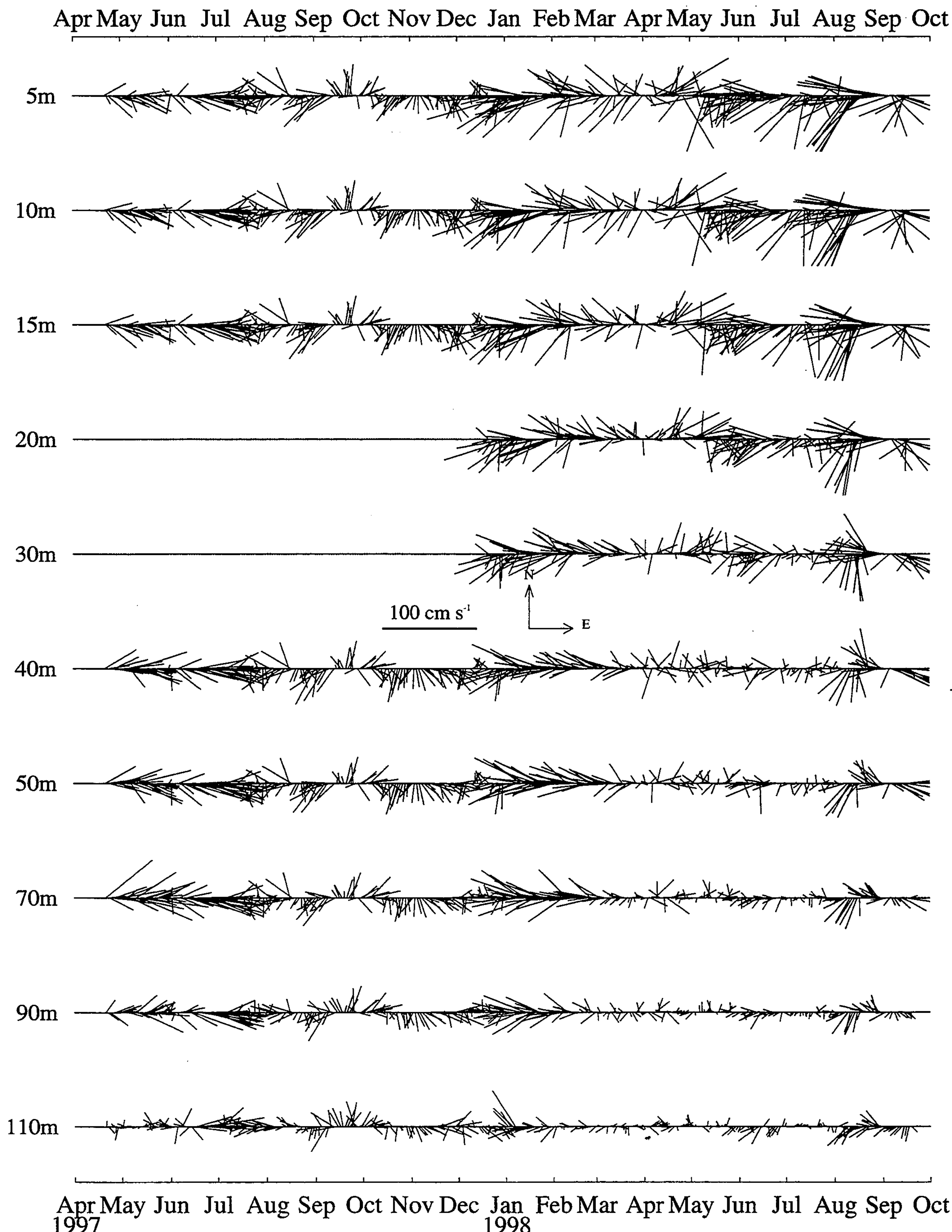


Figure 5-24. VMCM 36 hour vector averaged velocity.
(PACS South)

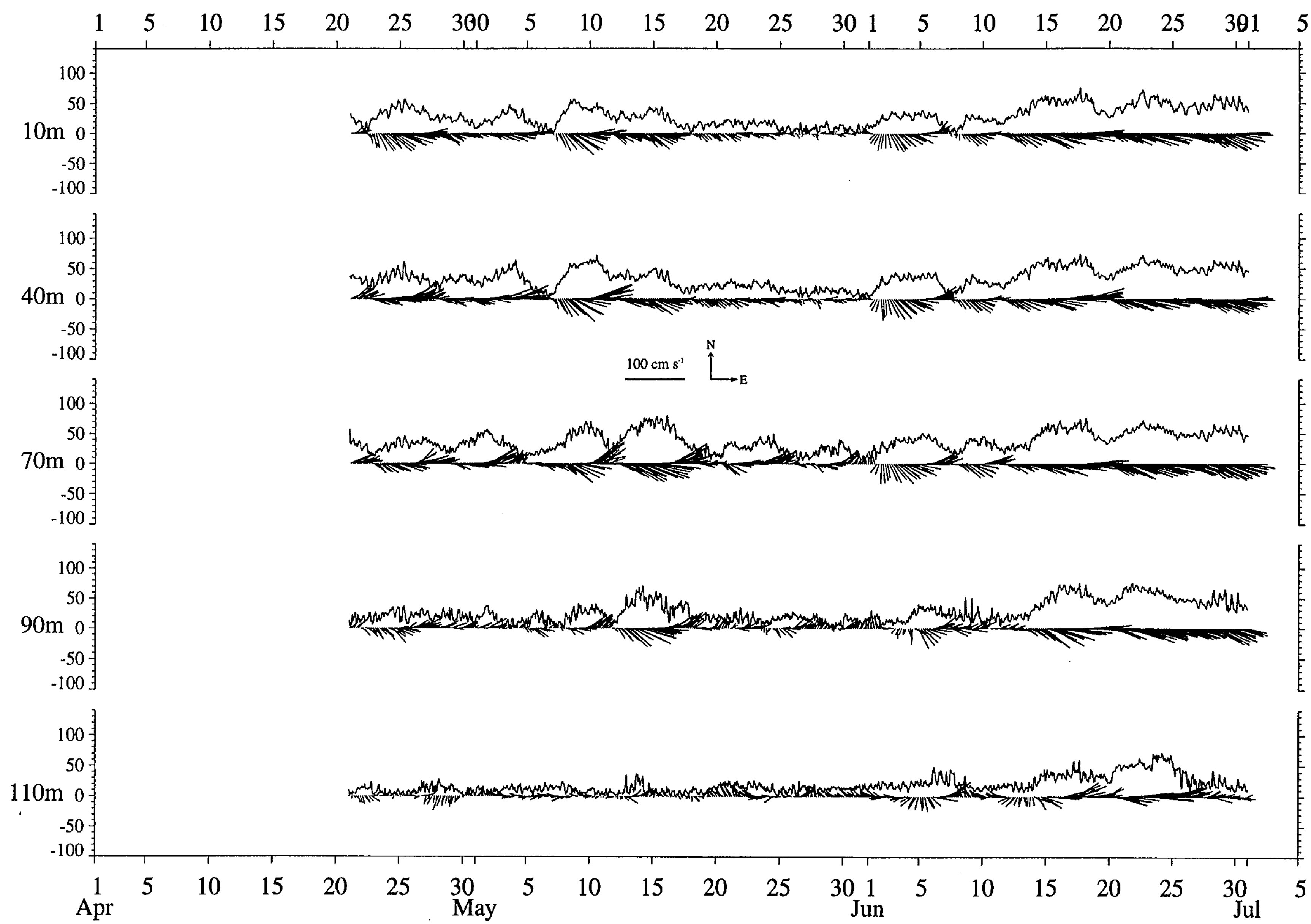


Figure 5-25. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for April through June 1997. (PACS South)

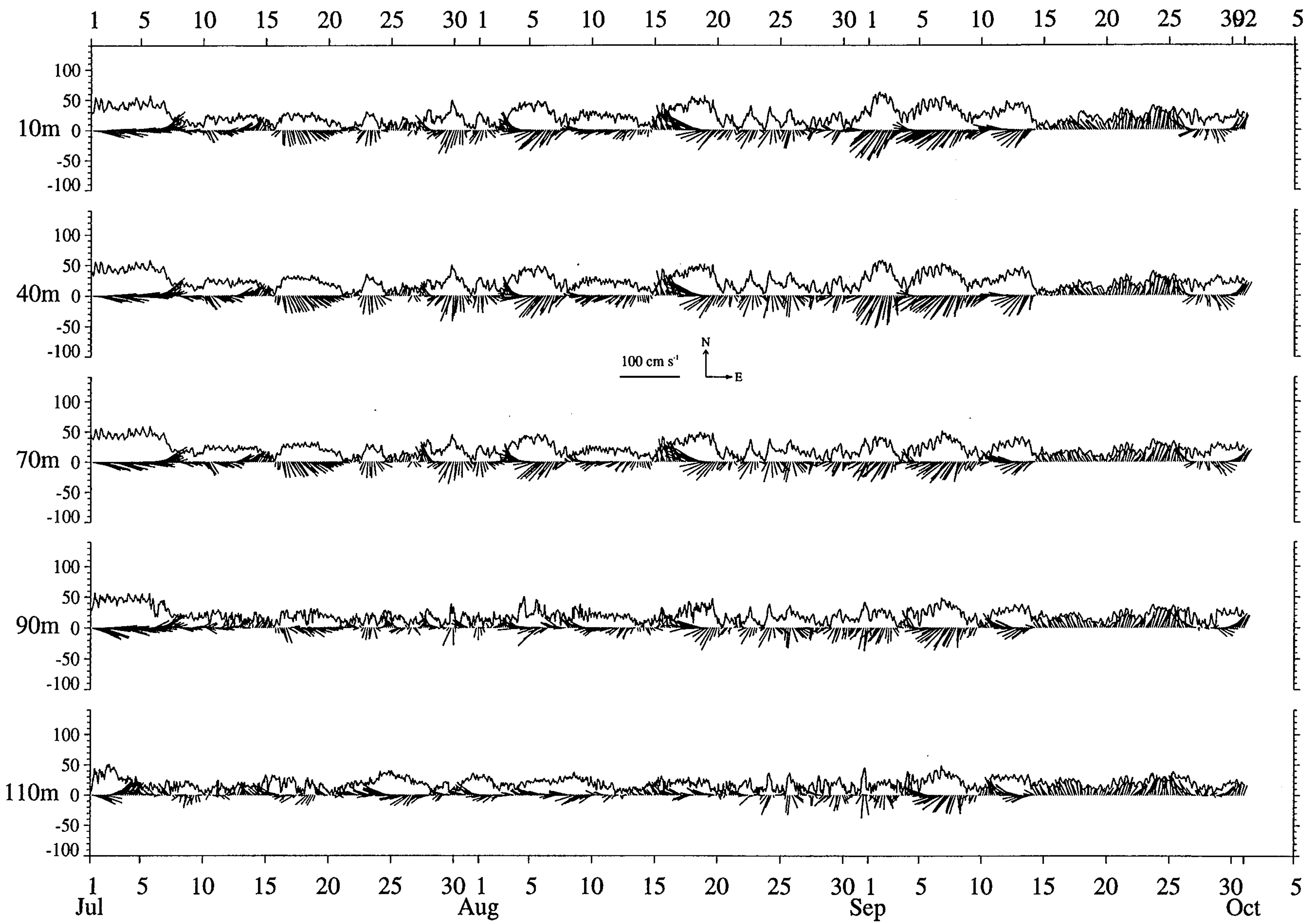


Figure 5-26. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for July through September 1997. (PACS South)

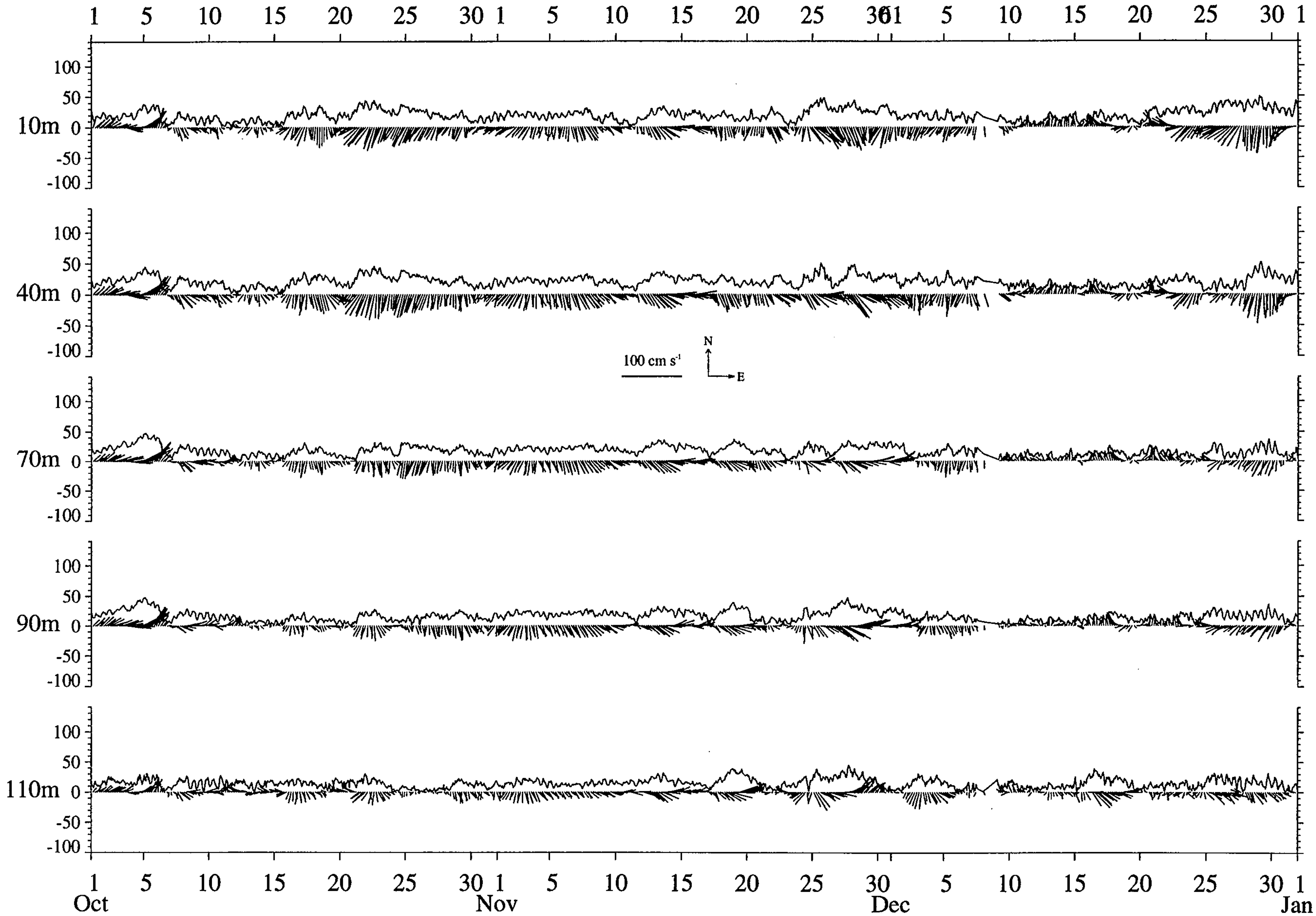


Figure 5-27. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for October through December 1997. (PACS South)

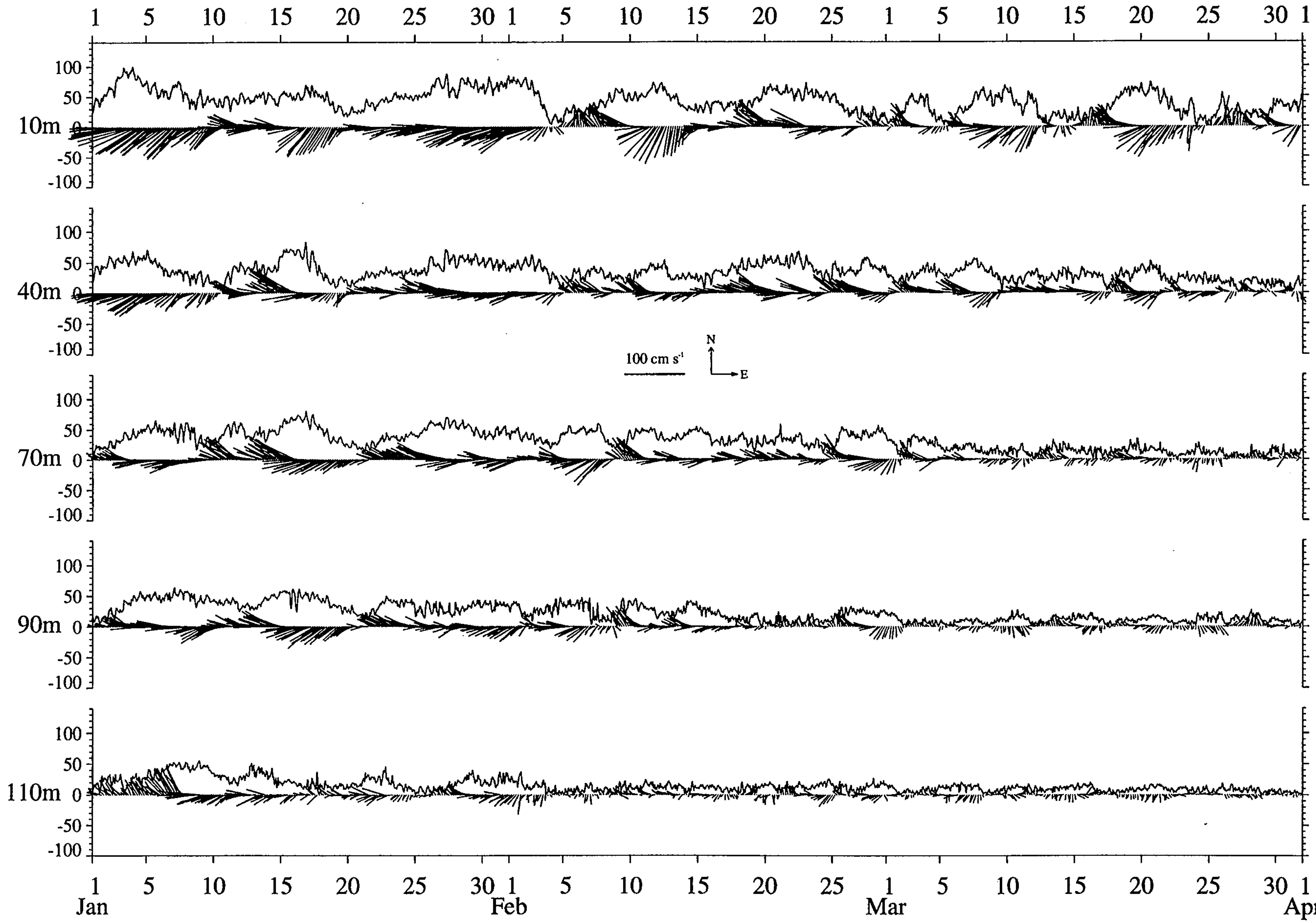


Figure 5-28. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for January through March 1998. (PACS South)

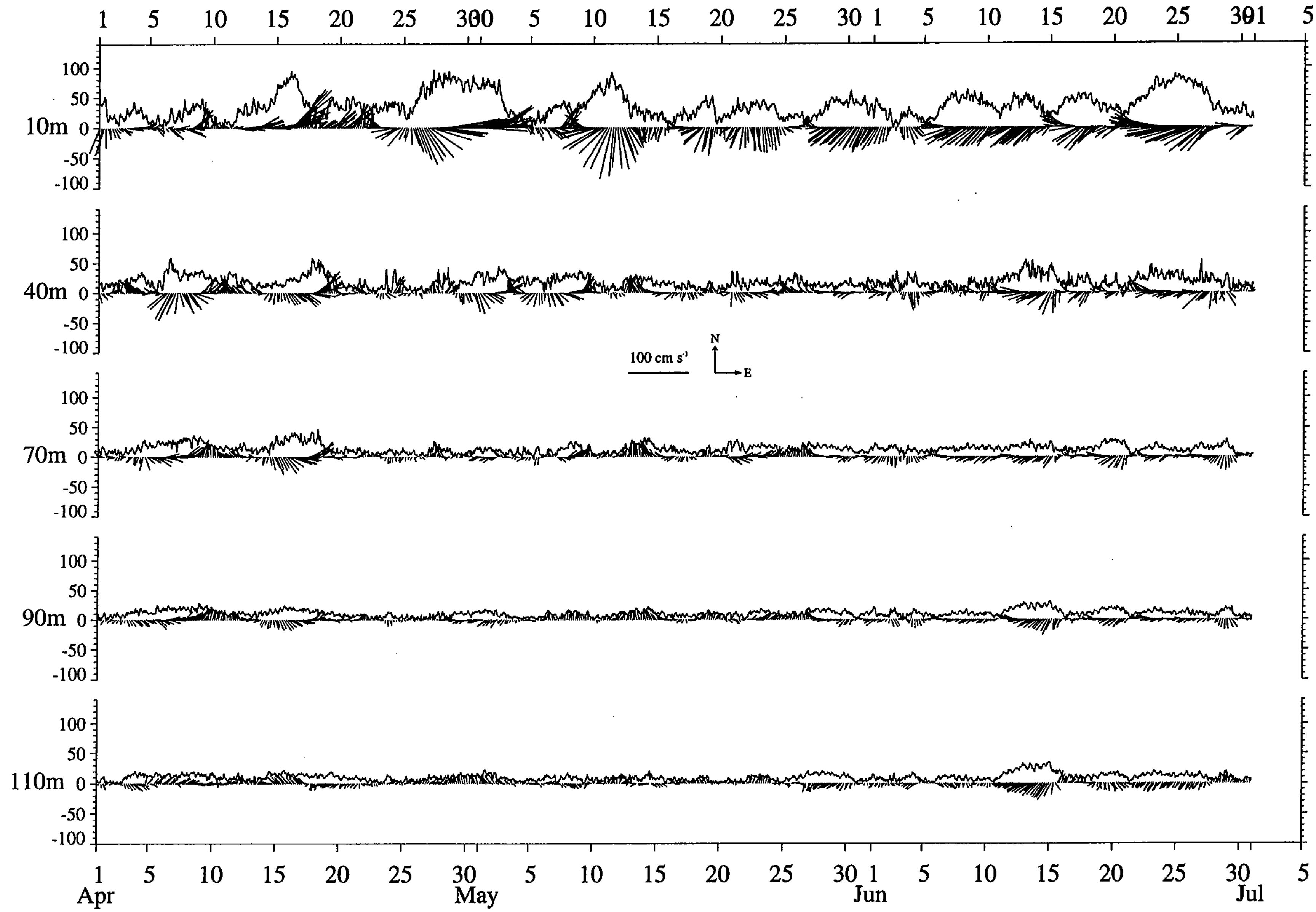


Figure 5-29. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for April through June 1998. (PACS South)

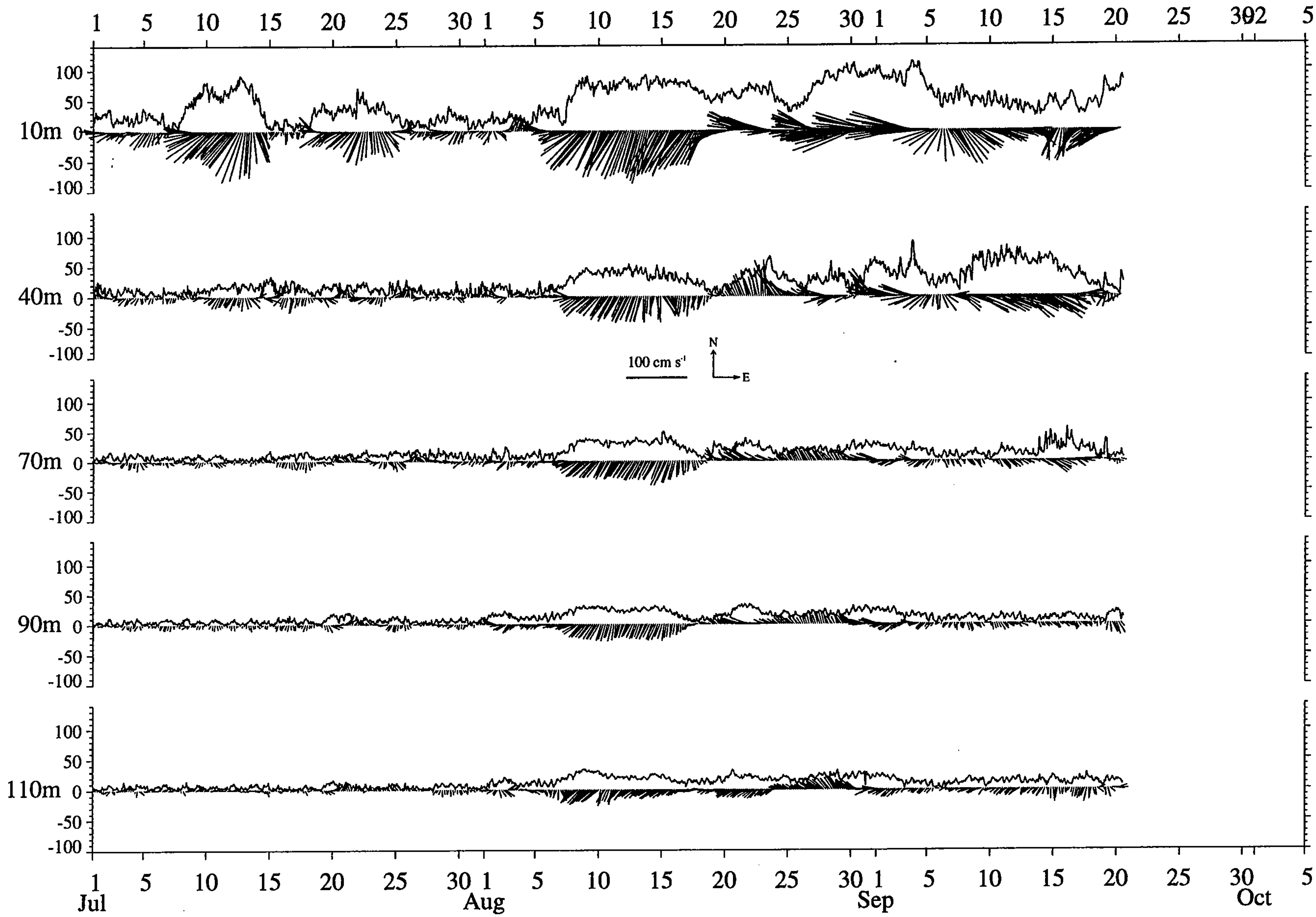


Figure 5-30. Four hour vector averaged velocity (sticks) and one hour current speed (line) in cm s^{-1} at selected depths for July through September 1998. (PACS South)

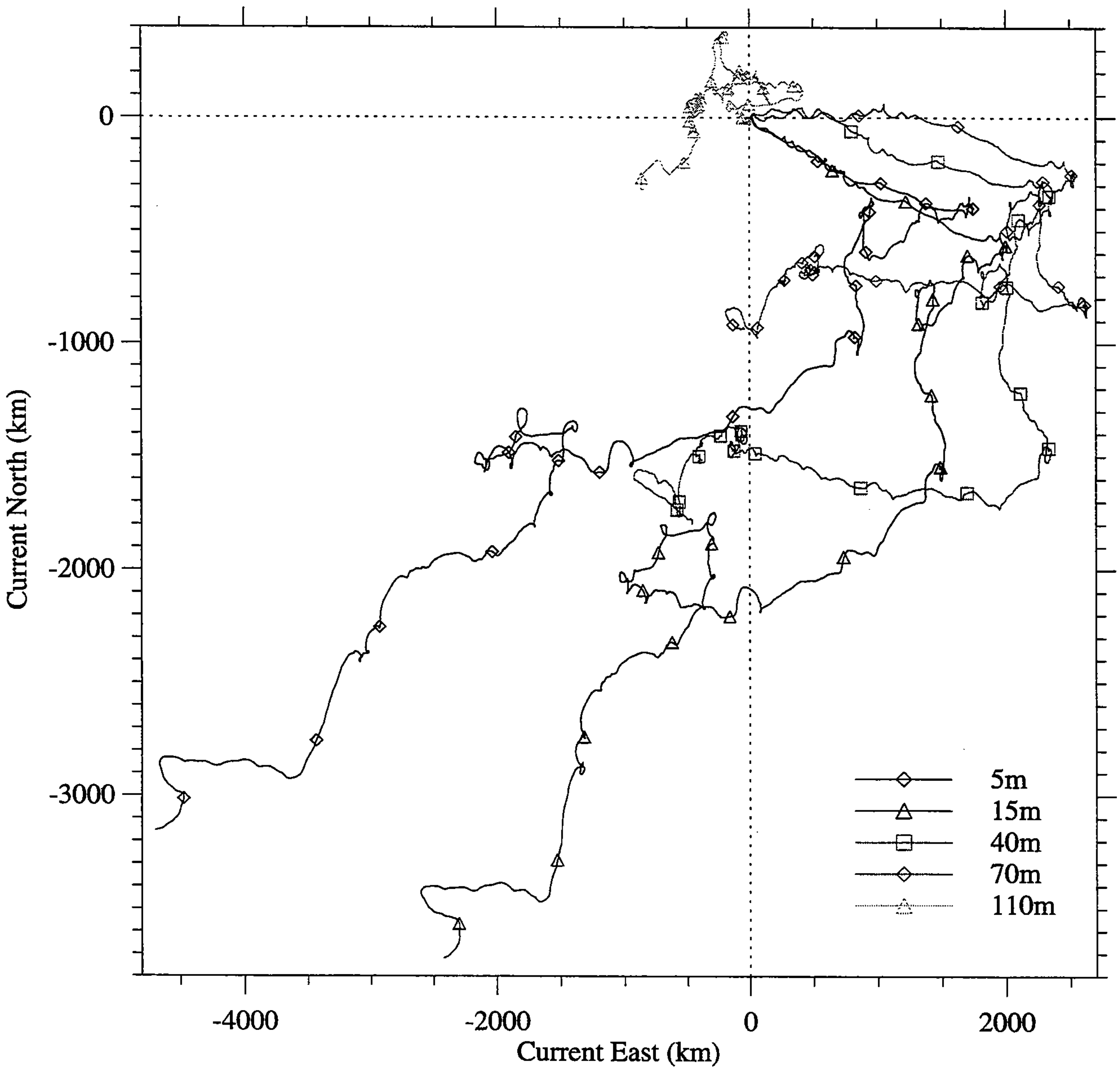


Figure 5-31. Progressive vectors from VMCM current meters. Symbols are placed 30 days apart. (PACS South)

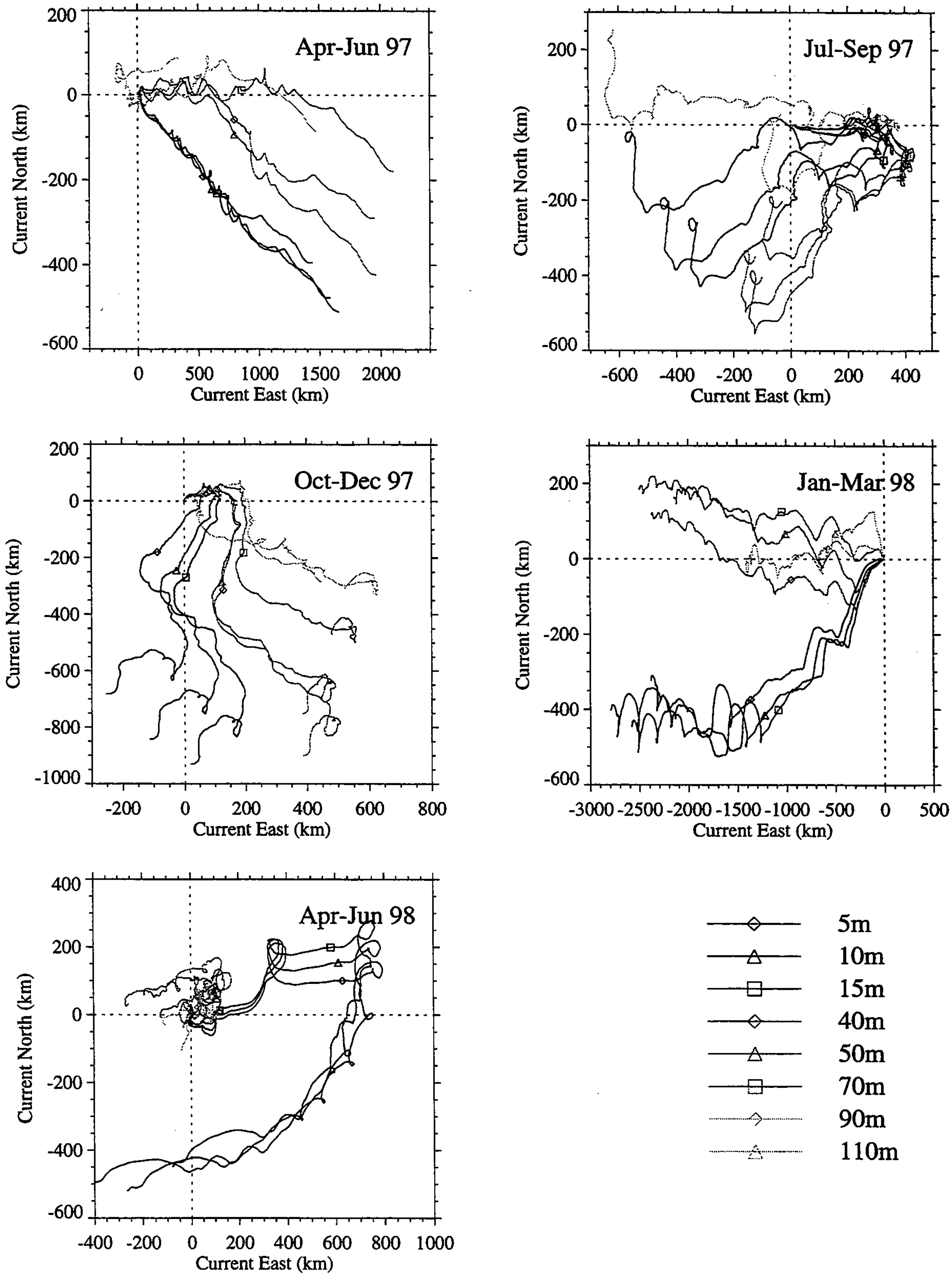


Figure 5-32. Progressive vectors from VMCM current meters. Symbols are placed 5 days apart. (PACS South)

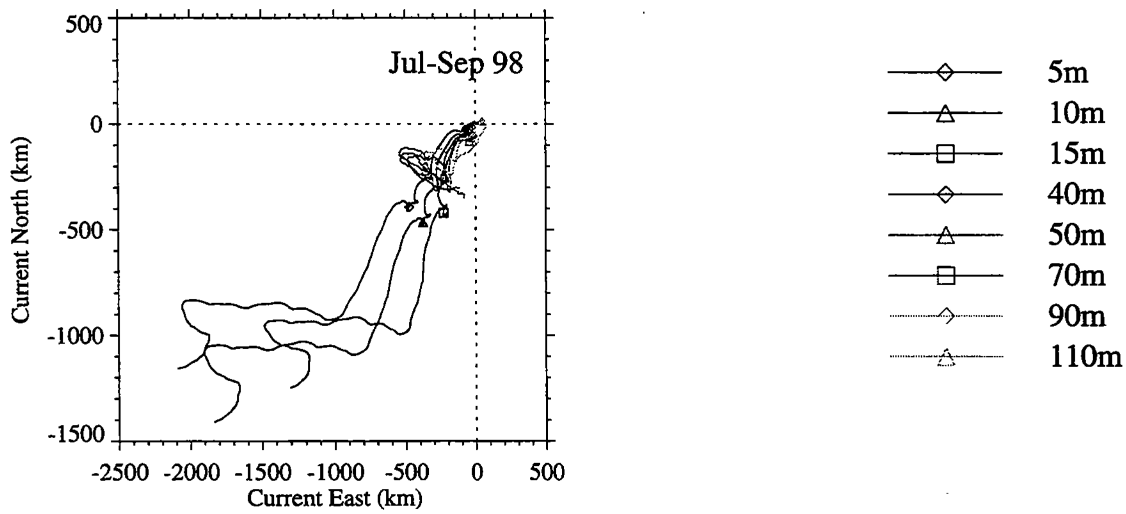


Figure 5-32. (continued)
(PACS South)

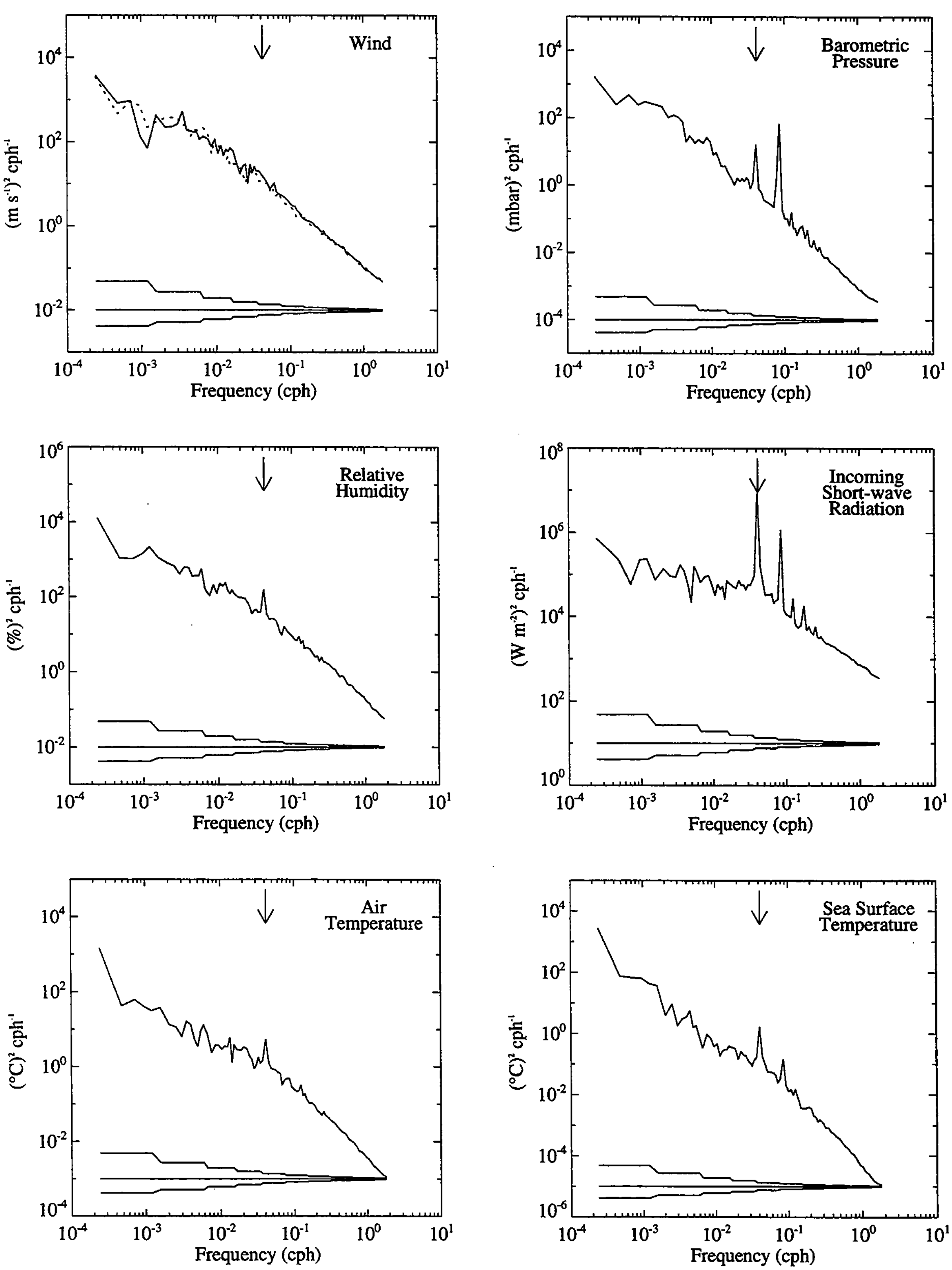


Figure 5-33. Autospectra of meteorological parameters. Rotary autospectra of the wind provides both clockwise (solid) and counter-clockwise (dotted) spectras. The arrow indicates the diurnal frequency (24^{-1} cph).

(PACS South)

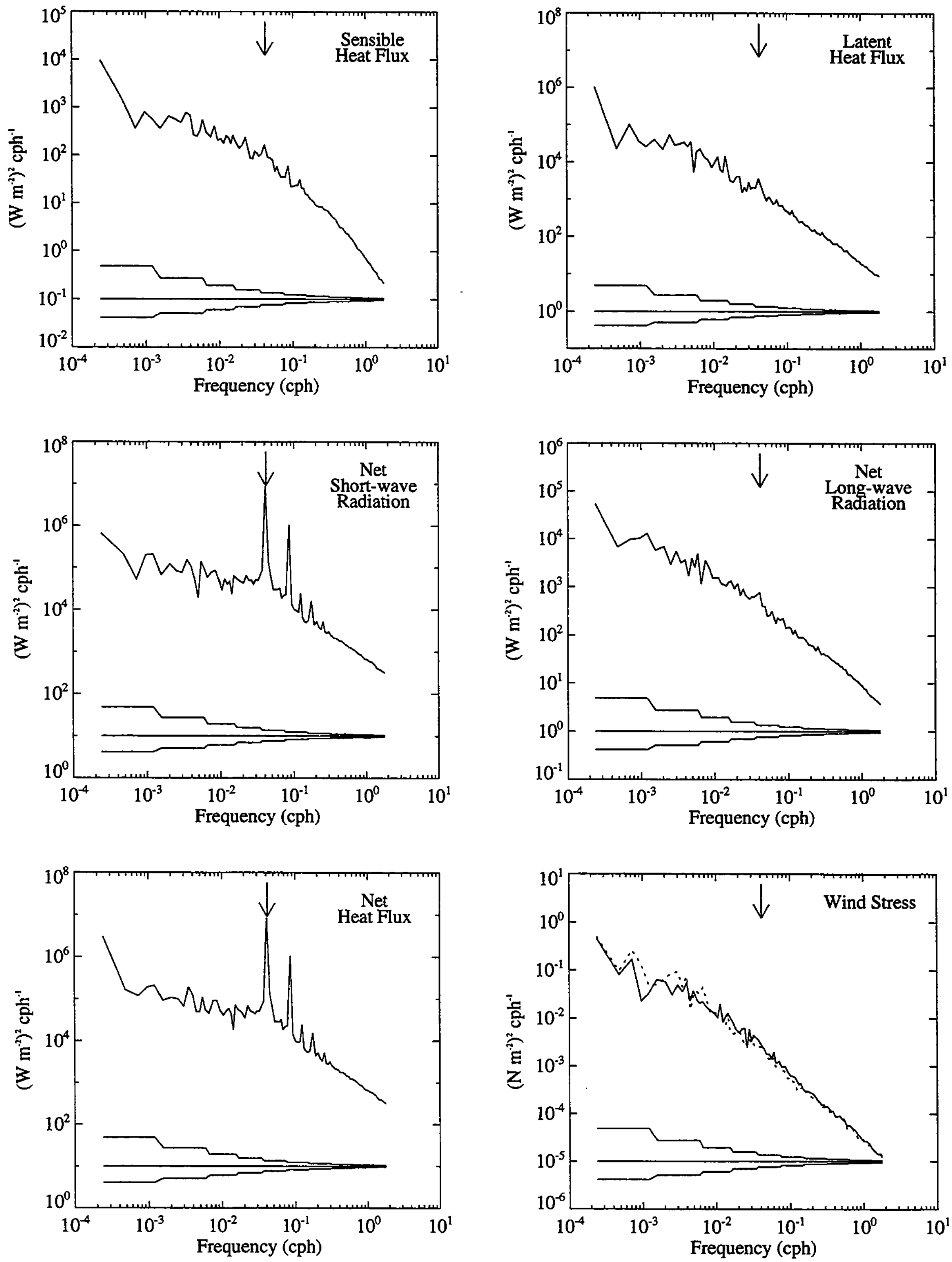


Figure 5-34. Autospectra of heat fluxes. Rotary autospectra of the wind stress provides both clockwise (solid) and counter-clockwise (dotted) spectras. The arrow indicates the diurnal frequency (24^{-1} cph).

(PACS South)

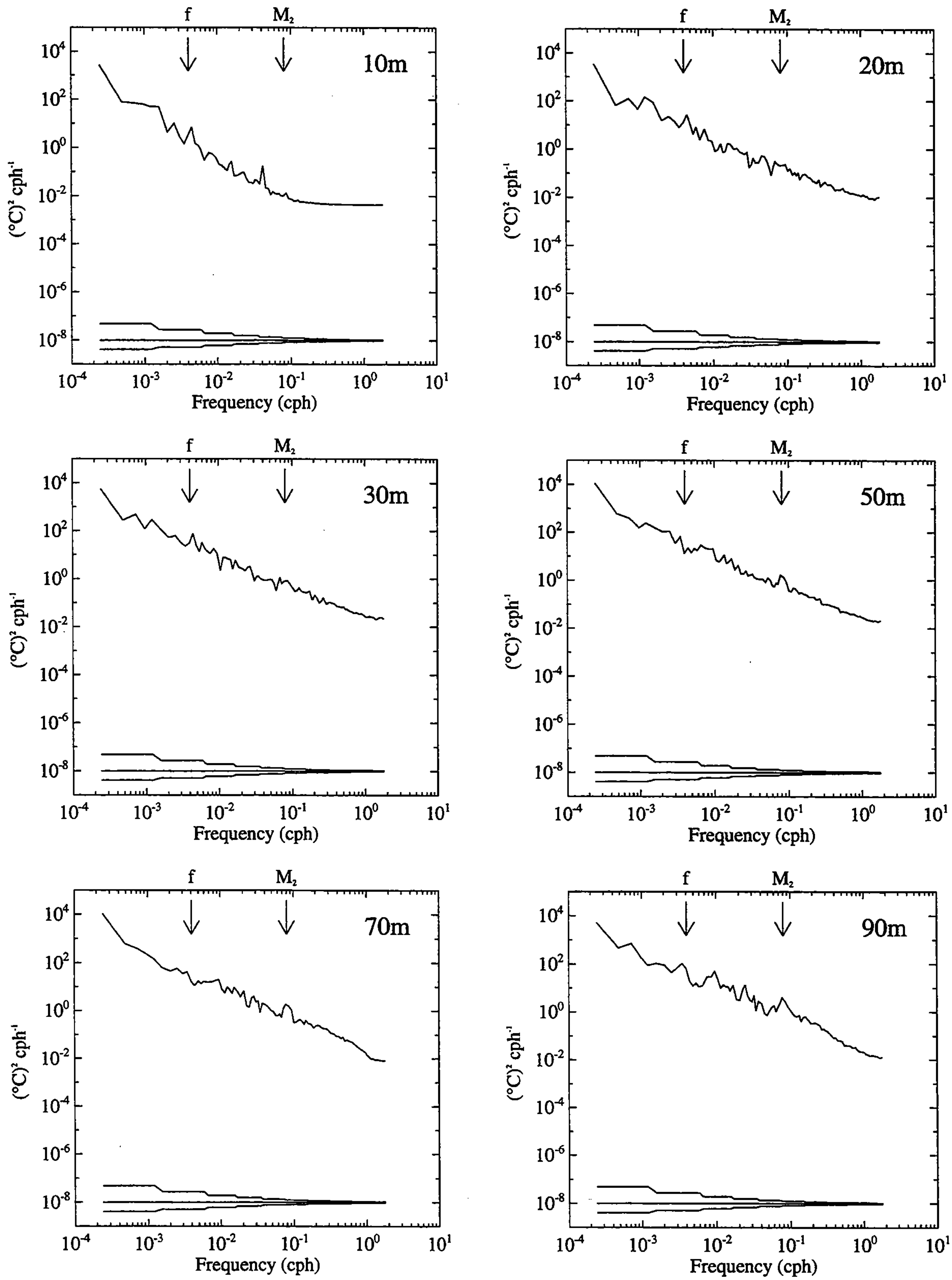


Figure 5-35. Autospectra of temperature at various depths. The tidal M_2 and inertial frequencies are indicated with arrows.

(PACS South)

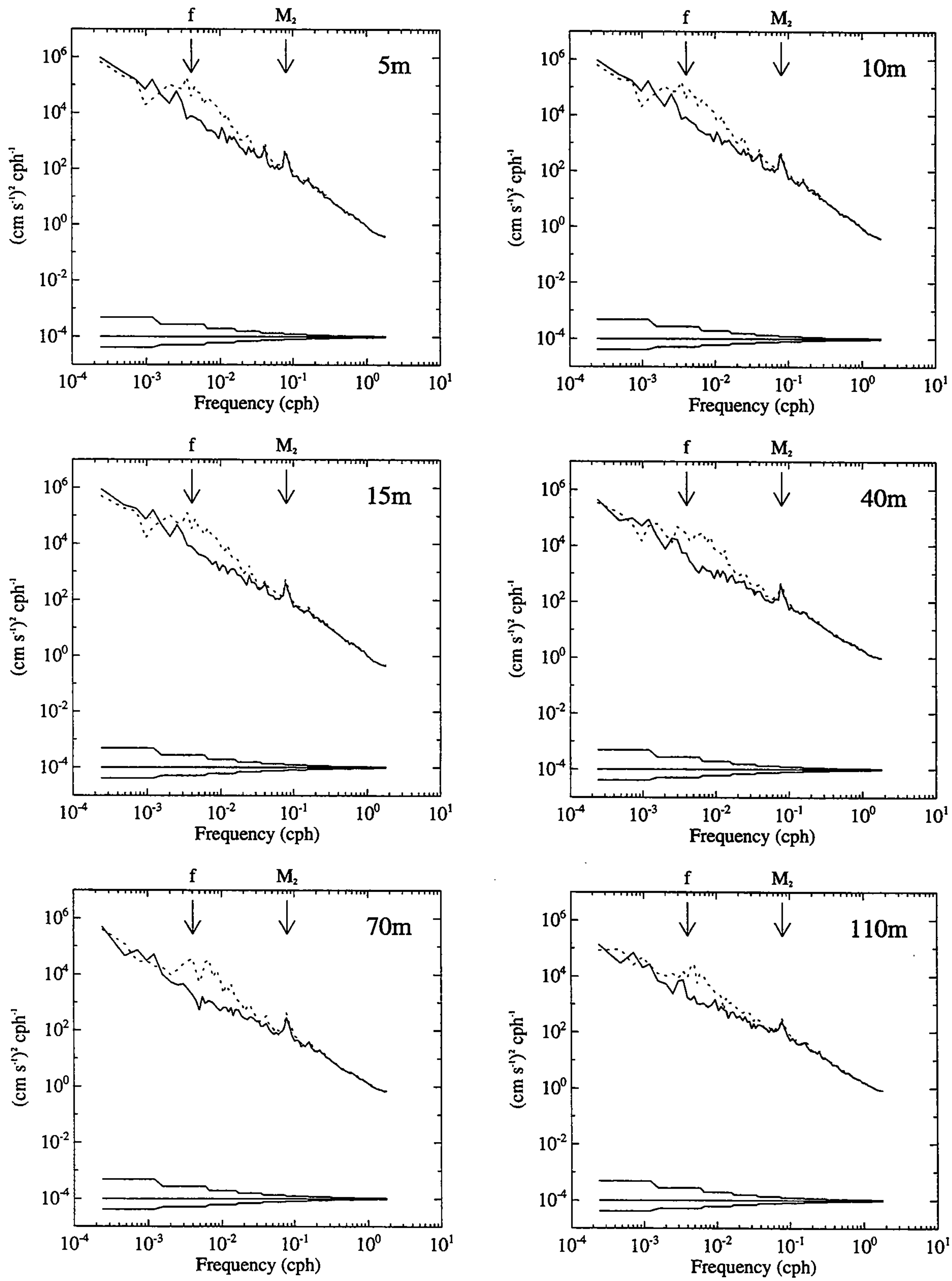


Figure 5-36. Rotary autospectra of velocity at various depths. The tidal M_2 and inertial frequencies are indicated with arrows. Clockwise spectra are solid and counter-clockwise spectra are dotted.

(PACS South)

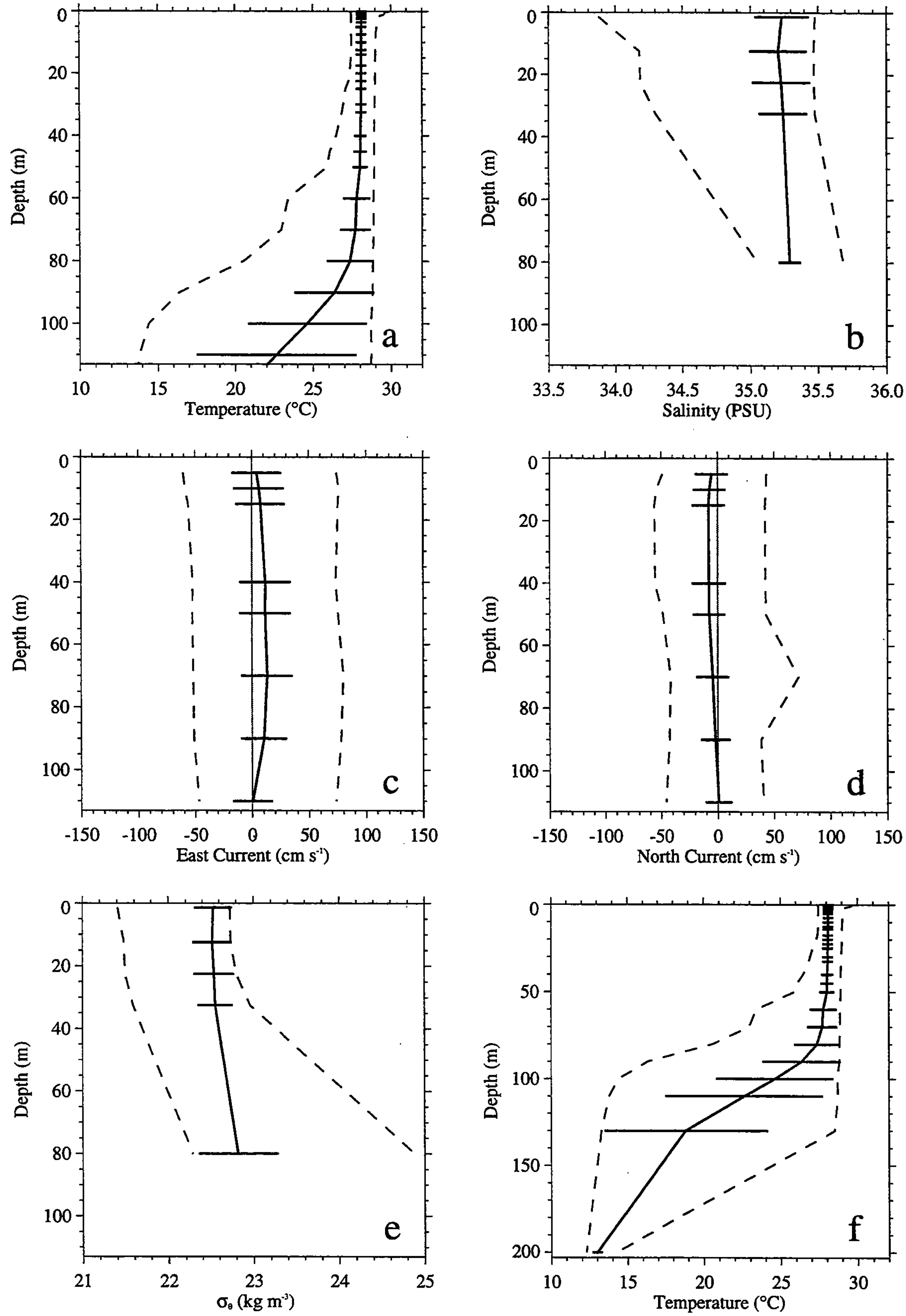


Figure 5-37. Mean profiles of April 1997 to December 1997 (horizontal bar indicates ± standard deviation, dash line indicates maximum and minimum range). (PACS South)

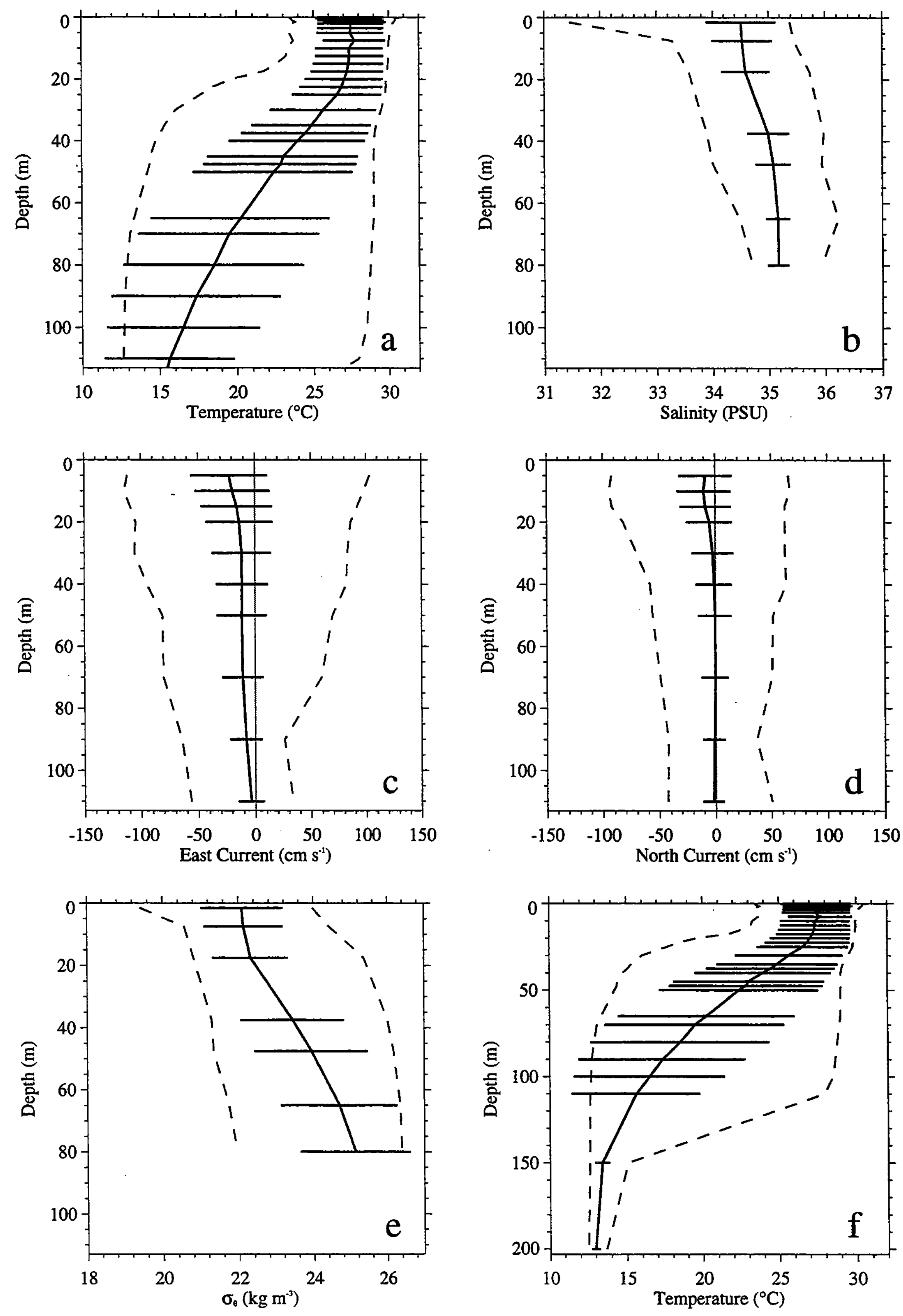


Figure 5-38. Mean profiles of December 1997 to September 1998 (horizontal bar indicates ± standard deviation, dash line indicates maximum and minimum range). (PACS South)

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References

Anderson, S.P. and M.F. Baumgartner, 1997. Radiative heating errors in naturally ventilated air temperature measurements made from buoys. *Journal of Atmospheric and Oceanic Technology.* **104**(C8), 18141-18158.

Baumgartner, Mark F., Nancy J. Brink, William M. Ostrom, Richard P. Trask and Robert A. Weller, 1997. Arabian Sea Mixed Layer Dynamics Experiment Data Report. Woods Hole Oceanographic Institution. Technical Report WHOI-97-08. 169pp.

Denbo, D. W. and W. H. Zhu, 1993. EPS Library User's Guide. Version 2.1. Pacific Marine Laboratory, National Oceanic and Atmospheric Administration. 131pp.

Fairall, C.W., P. O. G. Persson, E. F. Bradley, R. E. Payne, and S. A. Anderson, 1998: A new look at calibration and use of Eppley Precision Infrared Radiometers. Part I: Theory and application. *Journal Atmospheric and Oceanic Technology*, **15**, 1229-1242.

Fairall, C.W., E.F. Bradley, D.P. Rogers, J.B. Edson and G.S. Young, 1996a. Bulk parameterization of air-sea fluxes for TOGA COARE. *Journal of Geophysical Research.* **101**, 3747–3764.

Fairall, C.W., E.F. Bradley, J.S. Godfrey, G.A. Wick, J.B. Edson, and G.S. Young, 1996b: The cool skin and the warm layer in bulk flux calculations. *Journal of Geophysical Research.* **101**, 1295–1308.

Gill, G.C., 1983. Comparison testing of selected naturally ventilated solar radiation shields. Report submitted to NOAA Data Buoy Office, Bay St. Louis, Mississippi. In partial fulfillment of Contract #NA-82-0A-A-266. NOAA/National Data Buoy Center, Bay St. Louis, Mississippi, 39529, U.S.A.

Hosom, D.S., R.A. Weller, R.E. Payne and K.E. Prada, 1995: The IMET (Improved Meteorology) ship and buoy system. *Journal of Atmospheric and Oceanic Technology*. **12**, 527–540.

List, R.J., 1984. Smithsonian Meteorological Tables. Smithsonian Institution Press, Washington D.C. 572pp.

Liu, W.T., K.B. Katsaros and J.A. Businger, 1979. Bulk parameterization of air-sea exchanges of heat and water vapor including the molecular constraints at the interface. *Journal of the Atmospheric Sciences*. **36**, 1722-1735.

Ostrom, William M., Bryan S. Way, Steven P. Anderson, Brent Jones, Erica Key, Gabriel Yuras, and Bryan S. Way, 1999. Pan American Climate Study (PACS). Mooring Recovery Cruise Report, R/V *Melville* Cruise PACS03MV, 6 September to 30 September1998,Upper Ocean Processes Group, UOP Technical Report 99-01, Woods Hole Oceanographic Institution Technical Report, WHOI-99-06. 74 pp.

Payne, R. E., 1972. Albedo of the sea surface. *Journal of the Atmospheric Sciences*. **29**, 959–970.

Prada, K.E., 1992. A system for shipboard analysis of buoy data. Woods Hole Oceanographic Institution. Technical Report WHOI-92-42. 29pp.

Rew, R., G. Davis and S. Emmerson, 1993. NetCDF users guide: An interface for data access. Version 2.3. Unidata Program Center. 186pp.

Trask, Richard P., Robert A. Weller, William M. Ostrom and Bryan S. Way, 1998. Pan American Climate Study (PACS). Mooring Recovery and Deployment Cruise Report, R/V *Thomas Thompson* Cruise Number 73, 28 November to 26 December 1997,Upper Ocean Processes Group, UOP Technical Report 98-02, Woods Hole Oceanographic Institution Technical Report, WHOI-98-18. 107 pp.

Way, Bryan S., William M. Ostrom, Robert A. Weller, Jonathan D. Ware, Richard P. Trask, Rick Cole, and Jeff Donovan, 1998. Pan American Climate Study (PACS), Mooring Deployment Cruise Report, *R/V Roger Revelle,* Cruise Number Genesis 4, 9 April - 5 May 1997. Upper Ocean Processes Group, UOP Technical Report 98-01, Woods Hole Oceanographic Institution Technical Report 98-07, 71 pp.

Way, B.S., 1996: A stand-alone relative humidity and air temperature logger. Woods Hole Oceanographic Institution Upper Ocean Processes Group January 1996 Technical Note. Upper Ocean Processes Group, c/o Bryan Way, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543. 2 pp. Also available at http://uop.whoi.edu.

Weller, R.A. and R.E. Davis, 1980. A vector measuring current meter. *Deep Sea Research.* **27A**, 1122–1136.

Weller, R.A., D.L. Rudnick, R.E. Payne, J.P. Dean, N.J. Pennington and R.P. Trask, 1990. Measuring near-surface meteorology over the ocean from an array of surface moorings in the subtropical convergence zone. *Journal of Atmospheric and Oceanic Technology.* **7**, 85–103.

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16. Abstract (Limit: 200 words)

The surface mooring component of the NOAA Pan American Climate Study (PACS) took place from April 1997 to September 1998 in the eastern tropical Pacific. PACS was a NOAA funded study with the goal of investigating links between sea surface temperature variability in the tropical oceans near the Americas and climate over the American continents. Two air-sea interaction surface moorings were deployed along 125°W, spanning a strong meridional sea-surface temperature gradient. One mooring site was located in the cold tongue south of the equator, and the other site was in the region of warm ocean found north of the equator, near the northernmost summer location of the Intertropical Convergence Zone. The moorings were deployed to improve our understanding of air-sea fluxes and the processes that control the evolution of the sea surface temperature field in the region.

Four air-sea interaction buoys were deployed to occupy two sites for a period of 17 months. The sites were along 125°W near 3°S and 10°N. The Upper Ocean Processes Group at WHOI deployed the first two moorings in April 1997. These moorings were replaced with a second pair of moorings in December 1997. The final recovery occurred in September 1998. Each of these buoys on these moorings were equipped with meteorological instrumentation, including a Vector Averaging Wind Recorder (VAWR) and an Improved METeorological (IMET) system. The moorings also carried Vector Measuring Current Meters (VMCMS), single point temperature recorders and a few conductivity sensors on the mooring line to monitor the upper 200m of the ocean. In addition to the traditional instruments, several other experimental instruments were deployed with limited success on the mooring line including acoustic current meters, acoustic rain gauges and bio-optical instrument packages.

This report describes the instrumentation deployed on the PACS surface moorings, along with information on the processing and quality control of the returned data. It presents a detailed overview of the meteorological and physical oceanographic data including time series plots, statistics and spectra of key parameters. It also presents analysis of the estimated air-sea heat, moisture and momentum fluxes.

17. Document Analysis a. Descriptors

air-sea interaction

moored instrument measurements

PACS: eastern tropical Pacific

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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